Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2009**	2. REPORT TYPE	3. DATES COVERED **00-00-2009 to 00-00-2009**

4. TITLE AND SUBTITLE **RAND's Portfolio Analysis Tool (PAT): Theory, Methods, and Reference Manual**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Rand Corporation,1776 Main Street,PO Box 2138,Santa Monica,CA,90407-2138**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**127**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

This product is part of the RAND Corporation technical report series. Reports may include research findings on a specific topic that is limited in scope; present discussions of the methodology employed in research; provide literature reviews, survey instruments, modeling exercises, guidelines for practitioners and research professionals, and supporting documentation; or deliver preliminary findings. All RAND reports undergo rigorous peer review to ensure that they meet high standards for research quality and objectivity.

TECHNICAL REPORT

RAND's Portfolio Analysis Tool (PAT)

Theory, Methods, and Reference Manual

Paul K. Davis • Paul Dreyer

Prepared for the Office of the Secretary of Defense

RAND NATIONAL DEFENSE RESEARCH INSTITUTE

The research described in this report was prepared for the Office of the Secretary of Defense (OSD). The research was conducted in the RAND National Defense Research Institute, a federally funded research and development center sponsored by the OSD, the Joint Staff, the Unified Combatant Commands, the Department of the Navy, the Marine Corps, the defense agencies, and the defense Intelligence Community under Contract W74V8H-06-C-0002.

Library of Congress Cataloging-in-Publication Data

Davis, Paul K., 1943–
RAND's portfolio analysis tool (PAT) : theory, methods and reference manual / Paul K. Davis, Paul Dreyer.
p. cm.
Includes bibliographical references.
ISBN 978-0-8330-4887-5 (pbk. : alk. paper)
1. Strategic planning—Handbooks, manuals, etc. 2. Investment analysis—Handbooks, manuals, etc.
I. Dreyer, Paul, 1973– II. Title.

HD30.28.D3875 2009
658.4'012—dc22

2009040390

Published 2009 by the RAND Corporation
1776 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138
1200 South Hayes Street, Arlington, VA 22202-5050
4570 Fifth Avenue, Suite 600, Pittsburgh, PA 15213-2665
RAND URL: http://www.rand.org
To order RAND documents or to obtain additional information, contact
Distribution Services: Telephone: (310) 451-7002;
Fax: (310) 451-6915; Email: order@rand.org

Preface

This report documents RAND's portfolio analysis tool (PAT), which was developed at the RAND Corporation for the Department of Defense but should be useful in other strategic-planning organizations in government and the private sector as well. The report documents theory and methodology; it also serves as a combination reference manual and user guide. In a sense, it is a second edition, because PAT builds on an earlier application-specific tool, PAT-MD, which was developed for the U.S. Missile Defense Agency's Program Integration Office (MDA/PI) (Dreyer and Davis, 2005). Since PAT-MD was developed, however, we have enhanced it substantially and have used it in a number of very different projects for the Office of the Secretary of Defense, the Joint Staff, the U.S. Air Force, and the Department of Homeland Security. Because of these enhancements and expressions of interest by potential users outside of RAND, we undertook a start-to-finish revision of the documentation.

The approach to analysis enabled by PAT is oriented toward supporting high-level decisionmakers. The reasoning behind the approach is described in this report, most of which, however, is technical documentation that will be of interest primarily to analysts and those who manage analysis. The report assumes that the reader is at least moderately familiar with Microsoft Excel.

Since PAT is an evolving tool, questions and comments are especially welcome. They should be addressed to Paul K. Davis (pdavis@rand.org) or to the developer, Paul Dreyer (dreyer@rand.org). The PAT program has been used extensively but has not been exhaustively tested. The documentation was written using Excel 2003 (Windows) and 2004 (Macintosh); a few minor differences with Excel 2007 (Windows) are mentioned in footnotes.

This research was sponsored by the Office of the Secretary of Defense and conducted within the Acquisition and Technology Policy Center of the RAND National Defense Research Institute, a federally funded research and development center sponsored by the Office of the Secretary of Defense, the Joint Staff, the Unified Combatant Commands, the Department of the Navy, the Marine Corps, the defense agencies, and the defense Intelligence Community.

For more information on RAND's Acquisition and Technology Policy Center, contact the Director, Philip Antón. He can be reached by email at atpc-director@rand.org; by phone at 310-393-0411, extension 7798; or by mail at the RAND Corporation, 1776 Main Street, P.O. Box 2138, Santa Monica, California 90407-2138. More information about RAND is available at www.rand.org.

Contents

Preface ... iii
Figures ... ix
Tables ... xi
Summary ... xiii
Acknowledgments ... xxi
Abbreviations ... xxiii

CHAPTER ONE
Introduction ... 1
Background ... 1
  Strategic Planning and the Balancing of Investments ... 1
  Dealing with Uncertainty and Disagreement ... 2
Portfolio Analysis Tools ... 2
  Definitions ... 2
  Functionality of PAT ... 3
Report Structure ... 4

CHAPTER TWO
Overview of PAT ... 5
Inputs and Outputs ... 5
Concepts and Terminology ... 6
  Multicriteria Scorecards ... 6
  Multiresolution Thinking ... 7
  Translating Raw Measures of Value into Scores ... 7
  Aggregating Scores ... 8
  Extensibility: Allowing Custom Aggregation Methods ... 10
Navigation and Architecture: Inputs and Outputs ... 11
  Architecture and Navigation ... 11
  Inputs and Outputs ... 12

CHAPTER THREE
PAT Input Worksheets ... 17
Template Builder ... 17
Level 1 Data ... 17

Level 2 Data 18
Names of Measures and Options 18
Data on Option Effectiveness 18
Parameters Specifying the Nature of Scoring and Aggregation 19
Warning Comments 20
The Modify Summary Button 20
Level 3 Data 20
MRM Level 1 and Level 2 Data 21
Cost Data 23
Establishing Cost Structure 23
An Easier Approach to Structuring Cost Data 23
Customized Cost Calculations 23
Simplifications 25
Perspectives 25
The Basic Concept of Perspectives 25
Easier Ways to Create and Store Perspectives 27
Extended Perspectives 28
Template Builder 28

CHAPTER FOUR
PAT Output Worksheets 31
Summary Sheet 31
Structure of the Summary Sheet 31
Structuring Rows and Columns with Template Builder 36
Adding or Deleting a Column 36
Adding a Numeric Column of Level 2 Information 36
Altering Cost-Related Columns 36
Adding or Deleting Options 37
Cost-Effectiveness 37
Comments, Flags, and Warnings 38
Measure Weights 38
Buttons 38
An Illustrative Summary-Level Scorecard 38
Level 2 Drilldown Sheet 39
Level 3 Drilldown Sheet 42
Cost Data Sheet 44
Scatter Plot Sheet for Cost-Effectiveness Landscapes 45
Spider Charts Sheet 46
Multimeasure Spider Charts Sheet 47
Selected Details Sheet 48
Rankings Table Sheet 48

CHAPTER FIVE
Details of the Methodology 51
Basic Concepts and Definitions 51
Attributes of Investment Options 51

Measures and Submeasures (Level 1, 2, and 3 Measures), Raw Values, and Scores ... 53
Relative Cost-Effectiveness ... 54
Methods and Functions ... 54
Summary of Definitions ... 55
Alternative Methods ... 55
The Need for Alternative Methods ... 55
Goals Method ... 57
Weak Thresholds Method ... 59
Thresholds Method ... 60
Weakest Link Method ... 61
Rankings Method ... 61
Color-Coding in Scorecards ... 63
Colors for Thresholds, Weak Thresholds, and Weakest Link Methods ... 63
Colors for Rankings Method ... 63
Examples of Scoring and Aggregation Using Different Methods ... 64
Goals Method ... 65
Thresholds Method ... 66
Weak Thresholds Method ... 67
Weakest Link Method ... 67
Rankings Method ... 69

CHAPTER SIX
Marginal and Chunky Marginal Analysis ... 71
Introduction ... 71
Chunky Marginal Analysis for a Ballistic Missile Defense Example ... 72

CHAPTER SEVEN
Concluding Observations ... 77
Purpose and Function of PAT ... 77
Seeking Flexibility, Adaptiveness, and Robustness ... 77
PAT as Software ... 78
The Importance of the Measures and Methods ... 78
Next Steps ... 79

APPENDIX
A. Quickstart on Using PAT ... 81
B. Transferring Data from an Earlier Workbook ... 95
C. Editing and Neatening ... 97

References ... 99

Figures

S.1. Schematic View of PAT Summary Sheet xv
S.2. Drilling Down for Explanation xvi
S.3. Illustrative Composite Summary Sheet xviii
S.4. Cost-Effectiveness Landscapes for Two Perspectives xviii
2.1. PAT as a Black Box 5
2.2. Illustrative Output Types 6
2.3. Four Levels of Detail 8
2.4. Mapping of Raw Values into Scores 9
2.5. Menu of Input and Output Sheets 11
2.6. Tabs for Moving Among Sheets 12
2.7. Schematic of Summary Sheet 13
2.8. Schematic of Drilldown (Zoom) 14
2.9. Sample Output Displays from PAT 15
3.1. Level 1 Data 18
3.2. Level 2 Data Sheet 19
3.3. Level 3 Data Sheet 21
3.4. Cost Data Sheet 24
3.5. Illustrative Perspectives Cases 26
3.6. Using the Summary Sheet's Perspectives Menu 27
3.7. Query About Saving or Creating a New Perspective 28
3.8. Template Builder for a Simple Example 29
4.1. Illustrative Summary Sheet 32
4.2. Options Menu of Summary Sheet 33
4.3. Alternative Color Schemes for Scorecards 33
4.4. Sorting-Categories Menu of Summary Sheet (Example-Specific) 34
4.5. Sorting-Method Menu of Summary Sheet 34
4.6. MRM Menu of Summary Sheet 34
4.7. Scoring-Method Menu of Summary Sheet 34
4.8. Current-Perspective Menu of Summary Sheet (Example-Specific) 35
4.9. Discount-Rate Menu (Summary Sheet) 35
4.10. Cost Information in the Summary Sheet 37
4.11. Warning Flags in a Summary Sheet 38
4.12. Illustrative Summary Scorecard (Level 1) 39
4.13. Level 2 Drilldown Sheet 40
4.14. Compressed Version of Level 2 Drilldown for Measure 2 41
4.15. Level 2 Drilldown with Goals Method 41
4.16. Level 2 Drilldown with Rankings Method 41
4.17. Level 3 Drilldown for Measure 2.2 42

4.18. Level 3 Drilldown If Measure 2.2 Has a Threshold Value 43
4.19. Illustrative Total Costs Versus Time Chart 44
4.20. Illustrative Scatter Plot 45
4.21. Scatter Plot for the Simple Problem, Using Two Scoring Methods 46
4.22. Illustrative Spider Plot 47
4.23. Multimeasure Spider Plot 48
4.24. Selected Details Sheet 49
4.25. Rankings Table Sheet for Effectiveness or Relative Cost-Effectiveness 49
5.1. Schematic of PAT's Calculations 52
5.2. Score Versus Raw Value for Goals and Thresholds Methods 59
6.1. Cost-Effectiveness Comparisons for Two Perspectives 75
A.1. Overview of Summary Sheet 82
A.2. Illustrative Template Builder Sheet 84
A.3. Tug Bar for Viewing Separated Portions of an Excel Spreadsheet 90
A.4. Summary Sheet Excerpt for Exercise Problem 90
A.5. Level 2 Drilldown for Exercise Problem 91
A.6. Level 3 Drilldown for Exercise Problem 91
A.7. Scatter Plot of Effectiveness Versus Cost for Exercise Problem 92
A.8. Annotated Scatter Plot 93

Tables

2.1. Core Built-In Aggregation Methods 10
2.2. PAT Output and Input Sheets 12
2.3. Default-Ordered Listing of Tabs for PAT Sheets 13
5.1. A Glossary of PAT Terminology 55
5.2. Notation for Defining Scoring Methods 58
5.3. Mapping Measure Scores into Colors 64
5.4. Color-Coding in the Rankings Method 64
5.5. Summary of Methods 65
5.6. Illustration of Scoring Methods 65
5.7. Illustrative Results for the Goals Method 66
5.8. Illustrative Results for the Thresholds Method 67
5.9. Illustrative Results for the Weak Thresholds Method 68
5.10. Illustrative Results for the Weakest Link Method 68
5.11. Illustrative Results for the Rankings Method 69
6.1. Notional Probabilities of Intercept for Illustrative Problem 73
6.2. Performance of Options (Probabilities of Intercept) by Mission 73
6.3. Costs and Effectiveness Comparisons: Equal Emphasis on all Scenarios 74
6.4. Costs and Effectiveness Comparisons: Extra Emphasis on Peer Threat 74
A.1. Format for Entering Measure Names in Template Builder 85
A.2. Level 2 Data for Illustrative Exercise 88
A.3. Level 3 Data for Illustrative Exercise 89
A.4. Cost Data for Illustrative Exercise 89

Summary

Challenges of Strategic Planning

Strategic planning often seeks to balance investments across numerous objectives. Defense planners, for example, have objectives relating to force capabilities for future traditional and irregular warfare and for operations other than war. The objectives apply separately for different geographical regions and time periods. Acquisition planners have objectives of providing future weapon-system capabilities in each of many mission areas—again for different operational circumstances and time periods. Trainers have objectives such as preparing troops to operate in diverse missions and circumstances. None of these planners have the luxury of a single objective to be maximized. Rather, they are confronted and sometimes confounded by multiple objectives, few, if any, of which can be ignored. Nonetheless, choices must be made, because resources are finite.

Consequently, strategic planning often involves investing in a mix of capabilities and activities to address a mix of objectives. It is therefore natural to use the terminology of portfolio planning. The "portfolio" itself may be characterized by the allocation across investment categories (e.g., Army, Navy, Air Force; tanks, ships, and planes) or by the corresponding allocation across objectives (e.g., traditional versus irregular warfare). In either case, the idea is to *balance* the portfolio. This does not mean spreading money evenly across categories, because not all objectives are equal and because attending adequately to one may require much less effort than doing so for another. Further, given a large baseline of investment such as is enjoyed by the Department of Defense (DoD) and the Department of Homeland Security (DHS), among others, some ways of spending a marginal billion dollars provide far more leverage than others. Spending (or cutting) that marginal billion in proportion to the baseline patterns of expenditure is often irrational. Early in 2009, Secretary of Defense Robert Gates made this point as he proposed a defense budget that will rebalance the portfolio by shifting relatively small resources on the margin toward capabilities for irregular warfare and stabilization, security, transition, and reconstruction.

Dealing with Uncertainty and Disagreement

Against this background, portfolio analysis should assist decisionmakers to frame their thinking about balance, to construct good multifaceted options for consideration, and to make

subsequent choices.[1] Such analysis must include solid data and accurate calculations, but it also includes subjective inputs and analysis under deep uncertainty. Further, it must deal with the reality of major disagreements among senior leaders, disagreements that we can partially capture under the rubric of strategic perspective. A strategic perspective corresponds analytically to a way of weighing various objectives and priorities and assessing options' adequacy in meeting them. Much of this is about managing strategic risk. The essence of strategic decisionmaking is often either choosing a perspective or crafting options that will be valuable across important perspectives. Analysis can help by making perspectives-related issues explicit and, in some cases, by suggesting nuanced alternatives that are seen as having cross-perspective value.

RAND's Portfolio Analysis Tool

RAND's Portfolio Analysis Tool (PAT) was designed to facilitate strategic portfolio analysis dealing with both uncertainty and differences of perspective. It reflects lessons learned with earlier tools and has evolved considerably as the result of various RAND studies since 2005.

Comparing Options by Various Measures and by Cost

PAT generates high-level summary depictions for discussing issues of balance. It uses a spreadsheet-based format with options shown in rows and various measures of option goodness in columns. Figure S.1 indicates the structure of PAT's *Summary* sheet schematically. On the left is a five-color scorecard;[2] toward the right are optional columns for specific numerical outputs of interest in a summary; and still farther to the right are column groups for different depictions of cost and for overall effectiveness across measures and cost-effectiveness. At the top left are various "control panels" that allow the user to change the way underlying calculations are made, as well as a number of other items. At the lower left is a color bar that relates the colors to underlying effectiveness scores in a range from 0 to 1.

Drilling Down

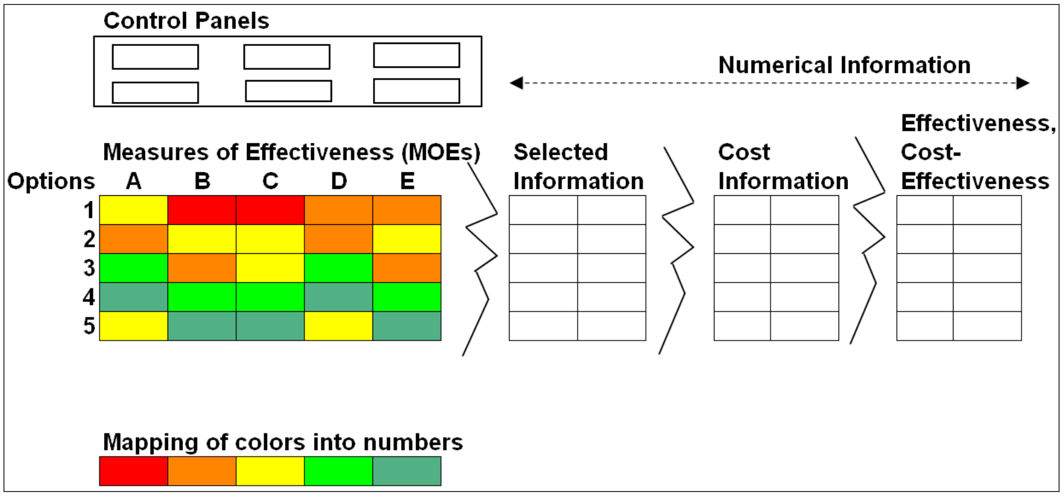
PAT makes it possible to drill down (zoom) to understand the basis of high-level characterizations and to put a spotlight on troublesome problems. The mechanism for what we call the drilldown function is shown schematically in Figure S.2, which indicates that the results shown for the Measure 2 column come from a lower-level (Level 2) calculation that considers two subordinate measures, M2.1 and M2.2. Similarly, the results shown for M2.2 come from an underlying calculation that considers Level 3 measures. A user looking at the *Summary* sheet can click on a column to bring up the Level 2 scorecard or go deeper to see the Level 3 scorecard of interest if such detail is provided.

Such drilldown can be part of interactive high-level presentations if a decisionmaker challenges a particular assessment out of interest or to test the depth of staff work. Alternatively, it

[1] The primary concepts are described elsewhere (Davis, 2002a; Davis, Kulick, and Egner, 2005; and Davis, Shaver, and Beck, 2008). The latter applies RAND's Portfolio Analysis Tool (PAT) to acquisition issues. Another publication (Davis, Johnson, Long, and Gompert, 2008) uses PAT in an assessment of alternative global strategies. Applications are ongoing with the U.S. Air Force and DHS.

[2] Red, orange, yellow, light green, and green denote very poor, poor, marginal, good, and very good, respectively. The underlying numerical scores may also be shown, but they are usually distracting and misleadingly suggestive of precision.

Figure S.1
Schematic View of PAT Summary Sheet



can simply be part of staff work ensuring that analysis is clear, well grounded, comprehensible, and accompanied by an audit trail. That is, undertaking a project with the expectation of using PAT can help structure the work along the way.

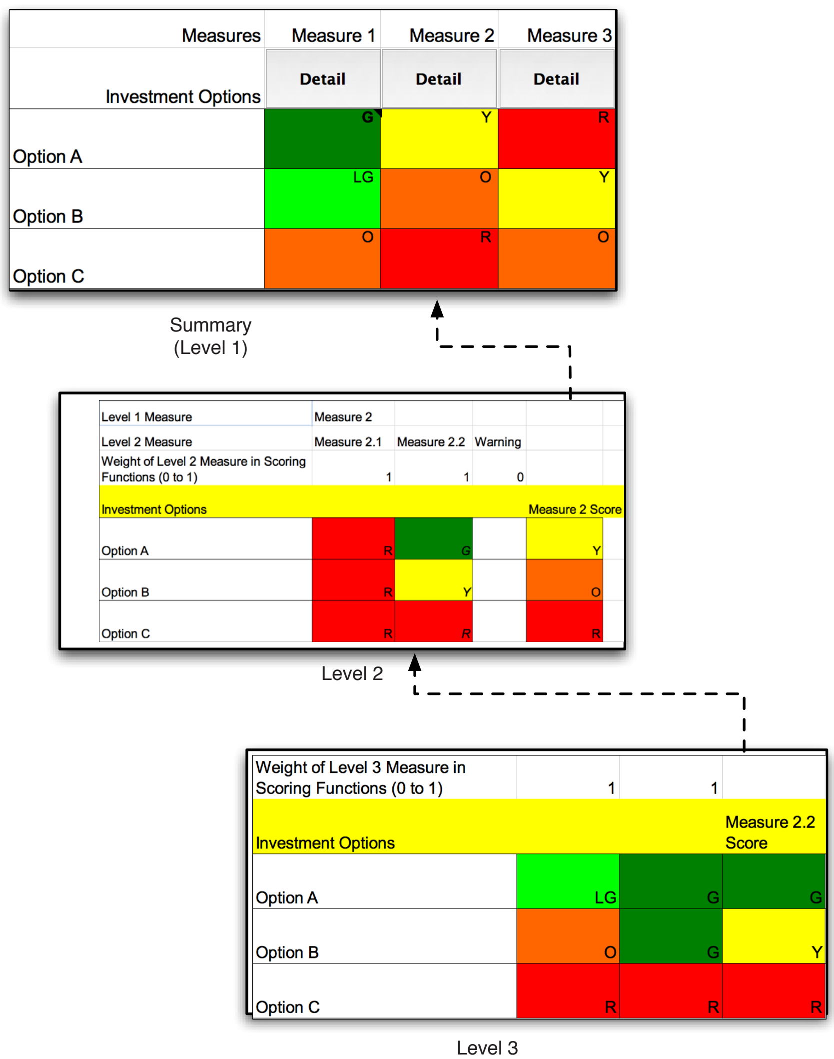
Alternative Combining Rules (Aggregation Rules)

High-level assessments depend on more detailed assessments, but how do they depend on them? When information is sent upward, as in Figure S.2, mathematical rules must be specified for doing so. Should lower-level assessments simply be averaged? Should linear weighted sums be used? What if the problem itself is not "linear"? Options for systems or strategies may have zero effectiveness in the real world if *any* of various critical components fail. A better weapon buys nothing if it cannot be delivered to the target. A stabilization strategy may fail if *any* of its political, military, or economic components is severely lacking—despite the quality of the other components. The natural measures in PAT analysis often include some that are individually critical and some that are important but perhaps substitutable. Recognizing such complexity, we designed PAT to accommodate a wide range of combining rules. Some are built in and can be chosen from a menu; others may be analyst-defined.

Alternative Perspectives

As discussed above, the concept of strategic perspective is important in framing issues and evaluating options. In our work with PAT, a strategic perspective translates into a coherent set of assumptions about the way objectives are weighed and assessments of capability for those objectives calculated and combined in aggregating from lower levels. One perspective, for example, might emphasize relatively near-term capabilities and activities along with currently relevant test scenarios, whereas another might emphasize longer-term matters and do so using test scenarios with intelligent adversaries responding to projected U.S. capabilities and vulnerabilities. Ultimately, perspectives differ in the value placed on various objectives, judgments about how much is enough, and the related matter of managing strategic risk. The user can also define "extended perspectives" that make distinctions based on, e.g., how the effectiveness of an option for a particular measure or submeasure is estimated.

Figure S.2
Drilling Down for Explanation



Multiresolution Data Entry and Modeling

A common problem in strategic decision support is that data—whether empirical and objective, the result of organizationally approved model calculations, or the result of the structured judgment of experts—can be overwhelming. Data can be the enemy of agile analysis intended for sharp, reductionist, high-level thinking. PAT is designed to enable data to be entered at alternative levels of resolution. Top-down thinking may begin with rather aggregated assessments, which may be quite sufficient for some purposes. Subsequently, more detailed assessments can be adopted, in which case, the aggregated-level results stem from those details. Alternatively, a bottom-up approach can be taken initially, but more aggregated inputs can be used for quickly addressing "What if . . .?" questions. In practice, greater detail is only some-

times justified and can even be misleading. A particular option's technological risk, for example, may best be judged at a high level, because that risk is the result of a myriad of problematic issues, not all of which are even identified.

Illustrative Outputs

An Illustrative PAT Summary Sheet

Figure S.3 shows an illustrative *Summary* sheet in which portions that may ordinarily be separated horizontally are juxtaposed. The left side of the sheet shows that options are being assessed by their effectiveness in two scenarios, A and B, and by something called "Other Measures," which might in a defense-planning context relate to something like shaping the international environment. The costs shown are total costs for a 20-year period. The effectiveness column shows an "overall" effectiveness across measures. Relative cost-effectiveness compares the cost-effectiveness ratio of an option with that of the most cost-effective option (except for treating the baseline as 0). We see that Option 2 is by far the most cost-effective (right column) but is still not satisfactory, as indicated by the yellow and red cells of the scorecard. To do well, however (Option 5), is quite costly.

As noted above, the values asserted for the aggregation of overall effectiveness depend not only on the assessments for each individual measure, but also on how those assessments are combined. Assumptions can be changed readily in either sensitivity analyses or more comprehensive exploratory analyses in which all key variables are varied simultaneously to explore what has been variously called the scenario space, outcome space, or possibility space. If such wide-ranging exploration has been accomplished first (whether crudely or in detail), the scenarios used to assess the options can be carefully defined analytically to stress the options in all of the ways regarded as important; i.e., they may constitute an approximate "spanning set." Current-day official planning scenarios do not typically have this virtue, but they could have it in the future. The number of test scenarios, of course, may be much larger than the number of scenarios in the illustrative examples in this report—at least at the working level, before simplifications are introduced for communicating efficiently to leadership.

Cost-Effectiveness Landscapes as a Function of Perspective

Displays such as Figure S.3 include a great deal of information. The scorecard information is especially important because decisionmakers need to understand how the options fare by different criteria (e.g., in the two scenarios). Balancing across such measures is fundamentally in the province of decisionmakers, and they are ill-served if they are presented only with super-aggregated information such as a nonintuitive single metric pretentiously called "effectiveness." So also, the drilldown feature is, in our view, essential.

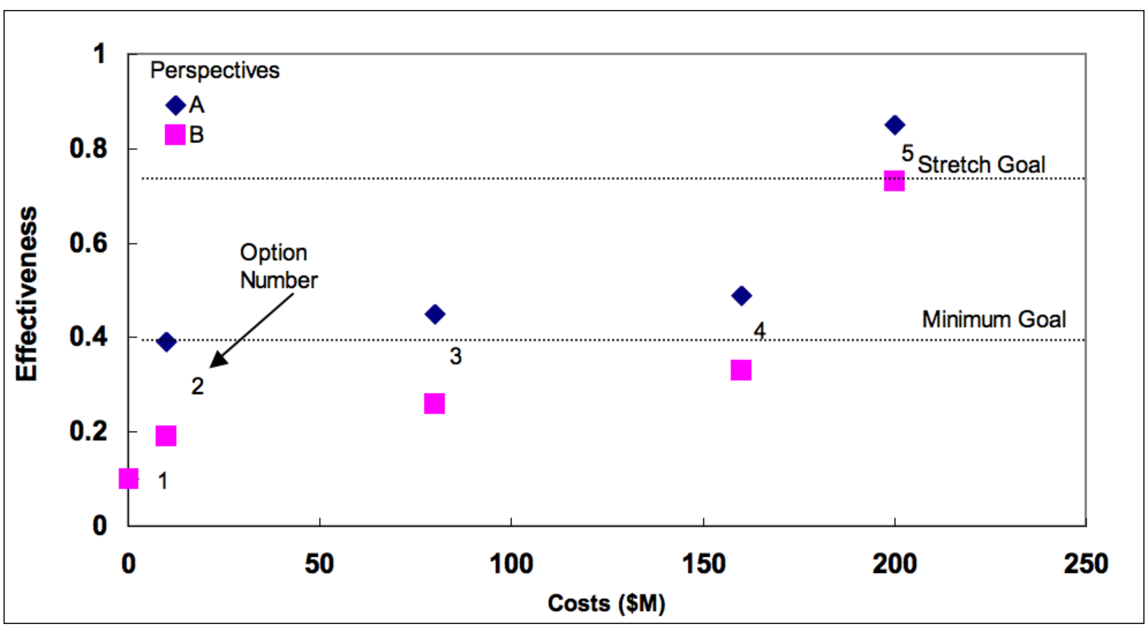
This said, *after* decisionmakers have oriented themselves adequately and discovered or asserted their preferences and the alternative strategic perspectives they wish to take seriously, it can be quite useful to generate visuals that exploit the simpler metric of overall effectiveness. This can be useful for communication and identifying marginal changes to improve cost-effectiveness. Figure S.4 illustrates this with what we call a "cost-effectiveness landscape." It plots the overall effectiveness and cost of each option and does so for each of two strategic perspectives (A and B). If enough well-chosen options have been considered, such a chart can communicate important information on what is gained as a function of expenditure. The results for

Figure S.3
Illustrative Composite Summary Sheet

Measures	Effect. in Scenario A	Effect. in Scenario B	Other Measures		Total Cost: 2010-2030 ($000s)	Effectiveness	Relative Cost Effectiveness
	Detail	Detail	Detail	Detail	Cost Detail		
Investment Options	1	1	1				
Baseline (Option 1)					0	0.1	0
Option 2					10	0.37	1
Option 3					80	0.48	0.16
Option 4					160	0.51	0.09
Option 5					200	0.85	0.12

Perspective A (upper, dark-blue diamonds) indicate that Option 2 is significantly better than Option 1 for little cost and that incremental improvements occur with expenditures (Options 3 and 4). Another big improvement occurs with the much more expensive Option 5. In contrast, in Perspective B, the options short of Option 5 have much less value. Perhaps Perspective B is based on more stressful missions and more conservative assumptions. Upon looking at such charts, one might choose to talk in terms of minimum and "stretch" goals, shown by the horizontal lines. The latter would be feasible only if a larger budget were forthcoming.

Figure S.4
Cost-Effectiveness Landscapes for Two Perspectives



Risk Management

Risk management is very important in strategic decisionmaking, so we note that PAT can depict various types of risk in a number of ways, e.g., with explicit top-level measures, with lower-level measures relating to more stressful versions of a test case, by showing consequences of more and less conservative combining rules, or with warning flags (as shown for Option 5 in Figure S.3).

Well-conceived work with PAT should convey a good sense of what is being assumed—a traditional objective in analysis. The goal in decision support, however, should be even higher. It is one thing to summarize for the decisionmaker the assumptions and risks associated with an option. The decisionmaker is better served, however, if he or she is presented also with options that mitigate or hedge against risks—even risks that seem unimportant under prevailing best-estimate reasoning. Wise decisionmaking is not about optimization for a set of assumptions; it is about finding strategies that are not only "likely" to be acceptably effective under nominal assumptions, but also flexible, adaptive, and robust.

Acknowledgments

The authors appreciate the careful reviews and constructive suggestions of colleagues Manuel Carrillo, Barry Wilson, and Duncan Long, as well as the many suggestions offered during the development of PAT by colleagues James Bonomo, Henry Willis, Russell Shaver, and especially Richard Hillestad, who developed a predecessor tool, DynaRank, that we used in designing PAT.

Abbreviations

BMDS	ballistic-missile defense system
CM	countermeasure
COMPOEX	Conflict Modeling, Planning and Outcome Experimentation
DHS	Department of Homeland Security
DoD	Department of Defense
DODF/DOFA	defense of deployed forces/defense of friends and allies
FYDP	Future-Years Defense Plan
GAO	Government Accountability Office
HD	homeland defense
JICM	Joint Integrated Contingency Model
JWARS	Joint Warfare System
MDA	Missile Defense Agency
MRM	multiresolution modeling
O&S	operations and support
PAT	Portfolio Analysis Tool
PSOM	Peace Support Operations Model
R&D	research and development
RDT&E	research, development, testing, and evaluation
SEAS	Synthetic Environments for Analysis and Simulation
STORM	Synthetic Theater Operations Research Model

CHAPTER ONE

Introduction

Background

Strategic Planning and the Balancing of Investments

The motivation for developing RAND's Portfolio Analysis Tool (PAT) was the importance of balancing investments across multiple objectives in strategic planning. This balance is important for planning in such distinct domains as the Department of Defense (DoD), the Department of Homeland Security (DHS), international business enterprises, and personal finance. Today's defense planners, for example, have objectives relating to force capabilities for future traditional and irregular warfare and for operations other than war. The objectives apply separately for different geographical regions and time periods. Acquisition planners have objectives of providing future weapon-system capabilities in each of many mission areas—again for different operational circumstances and time periods. Trainers have objectives such as preparing troops to operate in diverse missions and circumstances. None of these have the luxury of a single objective to be maximized. Rather, planners are confronted and sometimes confounded by multiple objectives, few, if any, of which can be ignored. Nonetheless, choices must be made, because resources are finite.

Consequently, strategic planning often involves investing in a mix of capabilities and activities to address a mix of objectives. It is therefore natural to use the terminology of portfolio planning. The "portfolio" itself may be characterized by the allocation across investment categories (e.g., Army, Navy, Air Force; tanks, ships, and planes) or by the corresponding allocation across objectives (e.g., traditional versus irregular warfare).[1] In either case, the idea is to balance the portfolio. This does not mean spreading money evenly across categories, because not all objectives are equal and because attending adequately to one may require much less effort than doing so for another. Further, given a large baseline of investment such as that enjoyed by DoD and DHS, among others, some ways of spending a marginal billion dollars provide far more leverage than others. Spending (or cutting) that marginal billion in proportion to the baseline patterns of expenditure is often irrational. Early in 2009, Secretary of Defense Robert Gates made this point as he proposed a defense budget that will rebalance the

[1] Soon after the end of the Cold War, it was useful for DoD to think in terms of balancing across the objectives of shaping the international environment (e.g., through alliances and forward deployment of U.S. forces), having capabilities appropriate for deterring or fighting wars in the near- to mid-term, and building future capabilities to deal with emerging threats and opportunities (what came to be called military transformation). An early analysis proposing such portfolio balancing was Davis, Gompert, and Kugler (1996). DoD's actual strategy was called Shape, Respond, and Prepare Now (Cohen, 1997); it specifically addressed all three objectives, despite the erroneous claim by outside observers that it was merely to build forces for two major regional conflicts of the sort considered plausible in that period.

portfolio by shifting relatively small resources on the margin toward capabilities for irregular warfare and stabilization, security, transition, and reconstruction.

Dealing with Uncertainty and Disagreement

Against this background, portfolio analysis should assist decisionmakers in framing their thinking about balance, constructing good multifaceted options for consideration, and making subsequent choices.[2] Such analysis must include solid data and accurate calculations, but it will also include subjective inputs and analysis under deep uncertainty. Further, it must deal with the reality of major disagreements among senior leaders, disagreements that we can partially capture under the rubric of strategic perspective. A strategic perspective corresponds analytically to a way of weighing various objectives and priorities and assessing options' adequacy in meeting them. Much of this perspective is about managing strategic risk. The essence of strategic decisionmaking is often either choosing a perspective or crafting options that will be valuable across important perspectives. Analysis can help by making perspectives-related issues explicit and, in some cases, by suggesting nuanced alternatives that are seen as having cross-perspective value.

Portfolio Analysis Tools

Definitions

We use the term "portfolio analysis tool" to mean a tool for comparing investment options according to a number of quantitative and qualitative criteria, including costs, upside potential, and downside potential (risk). In strategic planning, such a tool can generate holistic, top-down depictions of alternatives and their possible implications, perhaps over many years into the future. Such a tool can assist in balancing programs, either with a start-fresh approach or in marginal analysis, i.e., assessing where to add or subtract the marginal dollar.

RAND's approach to strategic portfolio analysis has evolved over the past dozen years. It has been applied at several very different levels of analysis:

- Force planning for the Office of the Secretary of Defense in the mid-1990s (Davis, Gompert, and Kugler, 1996; Davis, Kugler, and Hillestad, 1997)
- Strategic planning for the Missile Defense Agency (MDA)
- Acquisition-level planning for Prompt Global Strike (Davis, Shaver, and Beck, 2008)
- Resource-informed strategic assessments for the Joint Staff (Davis, Johnson, Long, and Gompert, 2008)
- Mission-level analysis for the U.S. Air Force and DHS (Davis, Hillestad, Long, Dreyer, and Dues, forthcoming).

Our mid-1990s work was based on DynaRank, a decision support system developed primarily by Richard Hillestad at RAND (Hillestad and Davis, 1998; Miller, 2007). A par-

[2] The primary references for this report's concepts regarding strategic-level decision support are Davis (2002a), Davis, Kulick, and Egner (2005), and Davis, Shaver, and Beck (2008). The latter includes an application of PAT to acquisition issues. Another recent publication—Davis, Johnson, Long, and Gompert, 2008—includes an application to assessment of alternative global strategies.

allel stream of RAND research at the time used the objectives-to-programs methodology.[3] An improved tool, PAT-MD, was developed for MDA (Dreyer and Davis, 2005), along with an integrated-capabilities model for missile defense, CAM-MD (Willis, Bonomo, Davis, and Hillestad, 2006). RAND's work for MDA motivated the Under Secretary of Defense for Acquisition, Technology, and Logistics to request development of a generic version of the approach and tool for capabilities analysis. That became PAT, the subject of this report.

Functionality of PAT

PAT is not a model in the usual sense; rather, it is a cross-platform spreadsheet tool (built in Microsoft Excel)[4] that facilitates planning by presenting information in a way that is useful to senior leaders. However, using PAT encourages a structured way of thinking that generates a conceptual model for the problem being analyzed. Further, PAT can use a variety of separate or embedded models as sources of input data. PAT is an empty vessel, but one with many useful features:

1. **Summary scorecards.** PAT generates stoplight charts, simple color-scorecard summaries of how options rate on a number of juxtaposed criteria, such as measures of capabilities, risks, upside potential, and costs. These criteria may be quantitative or qualitative, objective or subjective.
2. **Drilldown (zooming).** PAT generates its summaries from more detailed considerations, which can be viewed by drilling down to a level that provides assumptions, a terse logic, and a measure of rigor, even for qualitative assessments. Two levels of drill-down are available.
3. **Multiresolution modeling (MRM) and data entry.** PAT allows the analyst to enter data at a lowest level of detail or at one of two more-aggregated levels. Entering data at the more-aggregated levels reduces the amount of data entry greatly and is consistent with the time-honored analytic approach of working top-down (starting at a high level, then adding enriching detail where warranted). The data themselves may be generated by a multiresolution model or family of models.
4. **Sensitivity analysis and exploratory analysis.** PAT allows the analyst to quickly recognize key assumptions and to change them interactively. This may be done parameter-by-parameter or more broadly. These analyses are greatly facilitated by the MRM feature.
5. **Alternative aggregation methods.** PAT allows the analyst to quickly change how summary depictions are generated (i.e., how they are aggregated from details). Choices include, for example, simple linear weighted sums, some nonlinear "weakest link" methods, linear weighted sums with threshold constraints, and rank ordering. The analyst can also use customized aggregation rules; i.e., PAT is extensible. We have found that to be important in practice.

---

[3] A mid-1990s RAND tool, the objectives-to-programs methodology used utility functions and spreadsheet methods to arrive at a higher level of aggregation (unpublished work by Manuel Carrillo and Preston Niblack, 1996).

[4] This documentation is intended for Excel 2003 (Windows) and Excel 2007 (Macintosh), except for a few differences in Excel 2007 (Windows) (noted in footnotes), with which we have had relatively little experience. PAT will not work with Excel 2008 (Macintosh) because it does not support Visual Basic macros. However, Macintosh users can use PAT readily within a virtual machine, such as *Parallels Desktop*™ or *VMWare Fusion*™.

6. **Links to capability analysis and other sources of data.** PAT links to even more-detailed information, such as that of an embedded or connected capabilities model, data generated separately from a capabilities model, empirical data, or structured judgments.[5]
7. **Marginal analysis.** Although PAT emphasizes multiobjective scorecards, it also generates scores of overall effectiveness or cost-effectiveness. These can be used for marginal or chunky marginal analysis about how to spend (or cut) the next increment of funds.
8. **Ability to represent and contrast alternative perspectives.** PAT encourages analysts to deal explicitly with the serious differences of opinion and judgment that can be referred to as alternative perspectives. Results of PAT analysis can then be shown as a function of strategic perspective. There can be striking differences in implications for cost-effectiveness assessments.
9. **Facilitated operations.** At a mechanical level, PAT automates many tedious spreadsheet operations so that users can generate and manipulate portfolio-style scorecards and underlying detailed information quickly. It also provides a variety of built-in displays.

Report Structure

The report is organized as follows. Chapter Two introduces the principal concepts and terms in PAT and gives a schematic overview. Chapters Three and Four then describe PAT's input and outputs in user-manual detail. Chapter Five discusses selected theory and methods in more detail—especially aggregation methods and methods for marginal and chunky marginal analysis. Chapter Six wraps up with suggestions and cautions for users and with thoughts about future work. Appendix A is a QuickStart exercise for those who like to learn by doing. Appendixes B and C describe some practical hints for those who are actually using PAT.

[5] An embedded model might be implemented in a particular worksheet of the PAT workbook. A "connected" model might import data from a program written in a different language, such as Analytica® (a product of Lumina Decision Systems, Inc., [www.lumina.com]). We used such a connection approach in our work for MDA (Willis et al., 2006). A capability model built in Analytica (CAM-MD) could be exported to PAT-MD.

CHAPTER TWO

Overview of PAT

Inputs and Outputs

PAT takes a series of inputs and generates outputs in the form of portfolio-style tables and various charts and graphics (Figure 2.1). That is, viewed as a "black box," it primarily generates displays to describe implications of input information in a structured way.

Many of the inputs, such as the investment options to be compared, are what one might expect. A given investment option specifies expenditures in each budget category for each year covered by the analysis. This could include, e.g., separate expenditures in the budget categories of research and development (R&D), acquisition, and operations and support (O&S). Investment options may differ in what is to be developed and how fast, in what will be deployed operationally, and so on. Or they may differ because of alternative technical approaches or because of alternative strategies.

As shown in Figure 2.1, other inputs to PAT include capabilities, risks, and costs for each investment option, as well as "control parameters," which determine the form of the outputs, the assumptions and methods used for evaluation and aggregation, and so forth. They can strongly affect how the various options stack up in summary displays.

As indicated schematically in Figure 2.2, PAT's outputs include color-coded scoreboards, which compare options by different objectives or measures (Columns A, B, and C), with red indicating poor and green indicating good; tabular outputs on overall effectiveness and cost; and standard charts, such as charts of cost versus time. Many more types of output display are available or can be readily constructed; we describe those more fully in subsequent chapters.

Figure 2.1
PAT as a Black Box

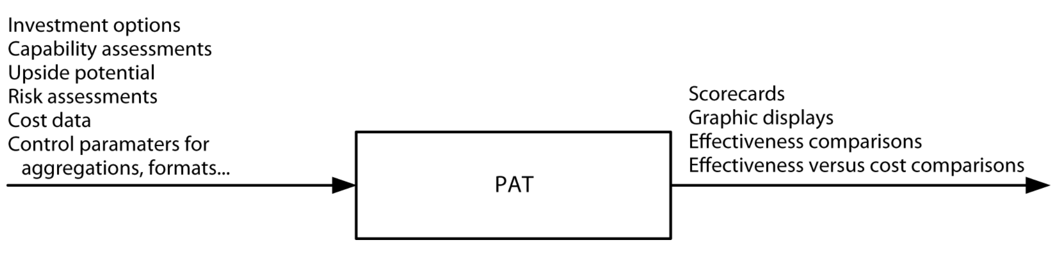
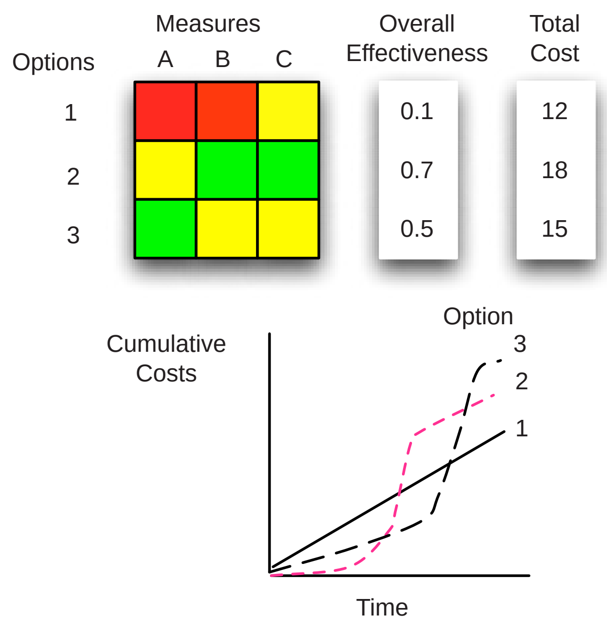


Figure 2.2
Illustrative Output Types



We next introduce a number of basic concepts and terms. Chapter Five provides a more complete and rigorous treatment.

Concepts and Terminology

Multicriteria Scorecards

Strategic planning typically requires evaluating options by multiple criteria. These criteria may relate to different objectives, operations, circumstances, time scale, and so on. They may include measures of risk and upside potential.[1] Although classic cost-effectiveness methods emphasize combining the effectiveness scores for different criteria to obtain a single variable to be optimized, modern policy analysis has long emphasized "policy scorecards," because decisionmakers need to see how the options fare by the different criteria.[2] The relative goodness of options may eventually be summarized in terms of a single index or utility, but that simplification should follow more discriminate reasoning with multiple criteria. The reason for this sequence is that the cross-cutting thinking across criteria is precisely what strategic decisionmakers are often most concerned about and most uniquely responsible for. Such thinking is not mere mathematical problem-solving.

[1] Both risk (essentially downside potential) and upside potential should be considered in good decisionmaking (Davis, Kulick, and Egner, 2005), but it is common (even in schoolhouses) for one or the other to be given short shrift, which biases the analysis.

[2] The late Bruce Goeller helped pioneer work on such policy scorecards in the 1970s (Goeller et al., 1983; Dunn and Kelly, 1991, pp. 133 ff).

It is cognitively efficient to use policy scorecards that are color-coded in the familiar way (red means bad, yellow means marginal, and green means good), although PAT has options for generating scorecards in other formats. Interestingly, such scorecards are sometimes criticized, but for reasons that do not apply to our usage. The primary problem is that officials are often briefed with scorecard-based analysis that is "one viewgraph deep," with little if any discussion of what (if anything) underlies the color-coding of results. Our approach is different.

Multiresolution Thinking

Four Levels of Detail. Each investment option can be evaluated in PAT at up to four levels of detail: (overall) effectiveness, Level 1, Level 2, and Level 3. Figure 2.3 illustrates this schematically with an example that we use throughout this report. Results at a given level are either specified directly or calculated from the next lower level (e.g., results from Level 3 "roll up" or aggregate to results at Level 2, and those from Level 2 aggregate to results at Level 1). This allows drilldown (zooming). That is, a result at one level can be explained by drilling down to deeper levels.

The focus of our work is at Level 1, Level 2, and Level 3. At these levels, PAT's displays assess the options by a number of criteria called "measures." At Level 1, for example, an illustrative measure might be effectiveness in Scenario A; another might be risks (i.e., downside potential, the potential for doing worse than is shown in the effectiveness columns). More extensive examples are presented later.

Multiresolution Data Entry. The straightforward way to build such a multilevel system of outputs is bottom-up, which typically means developing detailed data sheets. Those, however, can be tedious to build and to use, especially if uncertainty analysis is needed. Further, the complexity and detail of such sheets can result in errors as analysts vary assumptions. We designed PAT to have multiresolution data entry. This means that PAT maintains several data sheets. At any given time, PAT will run whichever data sheet is specified. The choices are called "Level 3" (which actually means that data can be entered at Level 2 or Level 3), "MRM Level 2," and "MRM Level 1." The labeling stems from the relationship to MRM.[3] We shall make this more concrete later with an example.

For agile exploration of changed assumptions, the analyst can use the *MRM Level 2 Data* sheet, because it has many fewer items to specify. Later, after understanding the issues better, he may revert to the more detailed work. It may also be that the analyst defers even developing a Level 3 description until after considerable work has been done at Level 2 to sharpen appreciation of where additional detail is actually useful. This is analogous to what many good designers, architects, and analysts do routinely: proceed top-down.

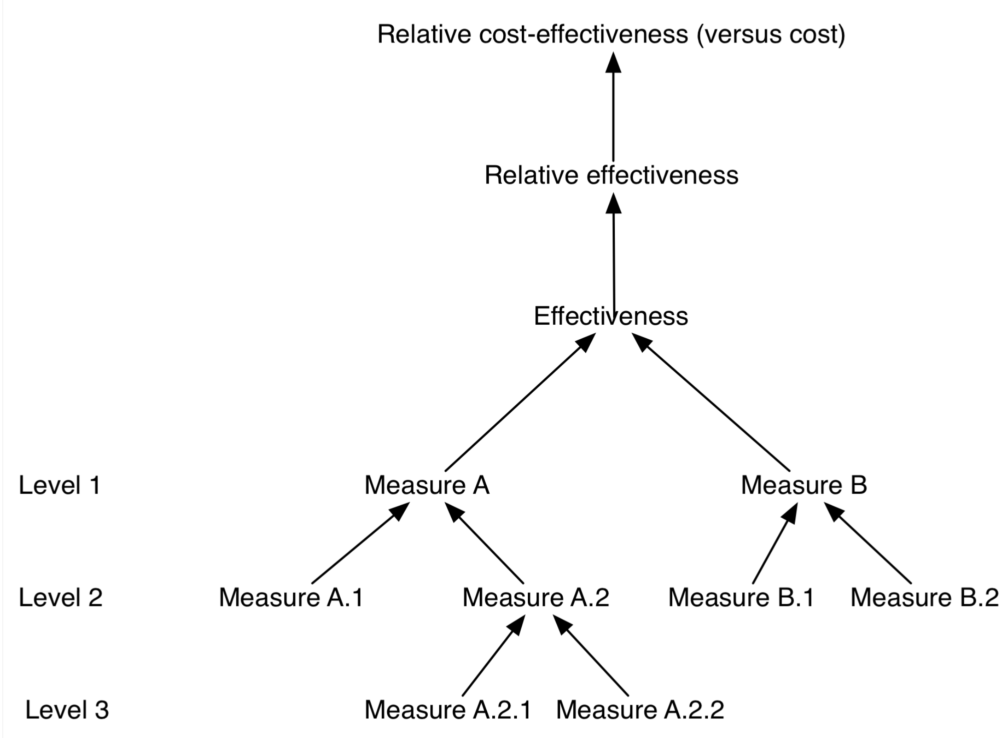
It is the analyst's responsibility to maintain consistency among the several data sheets.

Translating Raw Measures of Value into Scores

Any scorecard method (and any of the classic decision-analysis methods, such as those using utility functions) requires that the various measures of options' goodness be on a common

[3] The theory of MRM has evolved over the past 20 years (Davis and Huber, 1992; Davis and Hillestad, 1993; Bracken, Kress, and Rosenthal, 1995; Reynolds, Natrajan, and Srinivasan, 1997; Natrajan and Reynolds, 2001; Davis and Bigelow, 1998; Davis and Bigelow, 2003; Yilmaz and Ören, 2004). A number of detailed applications to defense problems have also been published (Davis, Bigelow, and McEver, 2001; Davis, 2002b; National Academy of Sciences, 1996; Davis, McEver, and Wilson, 2002).

Figure 2.3
Four Levels of Detail

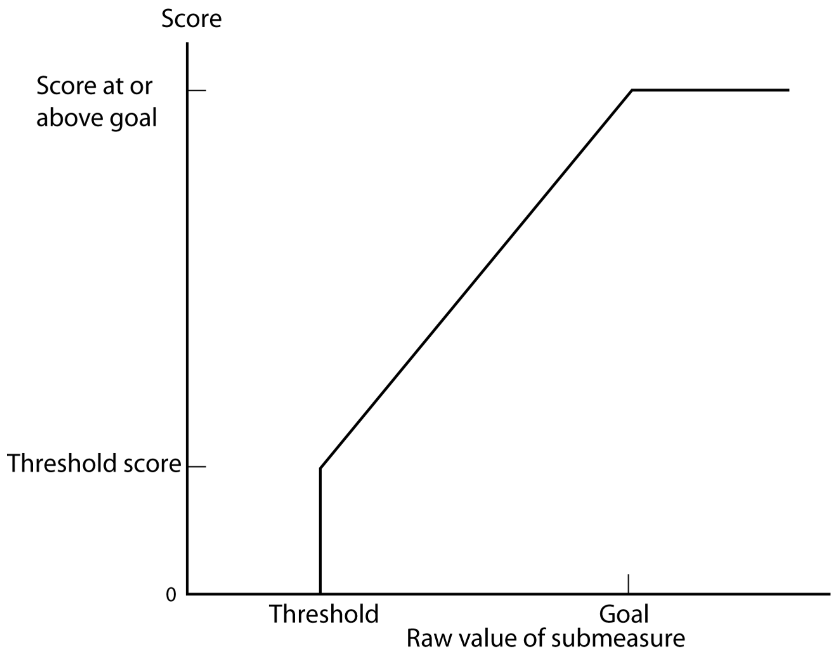


scale. This may be done quantitatively (e.g., on a 0-to-1 scale) or visually with a corresponding discrete set of colors (e.g., red, orange, yellow, light green, and green). Often, however, the *initial* measures are on heterogeneous scales. One measure may be in terms of probability (0 to 1); another may count something, such as the number of army divisions (perhaps 0 to 100) or estimate the expected lifetime of a weapon system (in years). Such initial measures are expressed in terms of *raw values*. PAT maps the raw values into *scores* by comparing them to thresholds and goals, as shown in Figure 2.4. Because we seek ultimately to describe options in discretized terms, the scores have lower and upper bounds: No matter how poor or good a raw value is, the score will never be lower than 0 or higher than 1. In some instances, a higher raw value is worse than a lower value (e.g., higher risk is considered bad). In such cases, we use a simple variant of Figure 2.4 (discussed in Chapter Five).

Aggregating Scores

Level 3 raw values are combined to generate Level 2 scores. Level 2 raw values, as well as computed Level 3 scores, are combined to generate Level 1 scores. At some point, the Level 1 scores are combined to generate a composite or overall score called "effectiveness." Cost-effectiveness can be calculated, or effectiveness can be shown as a function of cost (a better practice). Figure 2.3 illustrated the relationships schematically, showing relative cost-effectiveness as the most aggregate of the measures generated by PAT.

Figure 2.4
Mapping of Raw Values into Scores



Diagrams such as Figure 2.3 indicate with arrows that different measures combine to generate the score of a higher-level measure, but they do not say how they combine. It is frequently assumed in commercial decision-analysis tools and in introductory courses in decision analysis that factors combine via linear weighted sums. This is so common that it has affected our vocabulary, as when we refer to the relative "weight" of different input variables.

Linear weighted sums are often convenient and adequate, but they can be quite misleading, because in the real world, the combining rules are nonlinear. Do we want to be healthy or wealthy? No amount of health can compensate for extreme poverty and no amount of wealth can compensate for extreme illness. Overall utility is not a "sum" of scores for health and wealth, but something more complicated. Similarly, in designing a system or an investment program, the value of the whole may be essentially zero unless each of various critical components is sufficiently good.

Because of such considerations, PAT provides five built-in methods for establishing scores and aggregating upward. Ideally, only one such method would be needed, but theory and experience tell us that alternatives are needed—even more alternatives than the five built-in methods. Thus, we have also allowed for extensibility, as discussed later.

The five built-in methods are defined in Table 2.1, using the concepts of thresholds, goals, and nonlinearity. Chapter Five provides more details on all five methods. Of the five, the first three are the core methods, referred to as the Thresholds, Weakest Link, and Weak Threshold methods. The default method (Thresholds) characterizes a given aggregate measure's score as zero if any of its submeasures' scores are below analyst-specified thresholds. That is, a Level 1 measure is zero by this method if any of its Level 2 submeasures are below the threshold; similarly, a Level 2 measure is zero by this method if any of its Level 3 submeasures are below the threshold. This enforces the concept that a system fails if any of its critical components fail. The method is appropriate if the submeasures happen to be individually critical. The Weakest

Table 2.1
Core Built-In Aggregation Methods

Method	Component-Measure Scores	Aggregate-Measure Scores	Overall Effectiveness (across all measures)	Comment
Thresholds	See Figure 2.3	0 if any raw value does not reach threshold; otherwise, a weighted sum of component-measure scores	Weighted sum of measures' scores	Appropriate if component measures represent critical components of capability
Weakest Link[a]	See Figure 2.3	Minimum of component-measure scores	Minimum of measures' scores	Appropriate if both component measures and measures are individually critical
Weak Thresholds	See Figure 2.3	Weighted sum of component-measure scores	Weighted sum of measures' scores	Appropriate if thresholding is valuable but not all component measures or measures are critical
Goals		Weighted fraction of the component-measure goals achieved by option	Weighted sum of measures' scores	
Rankings		Borda ranking[b]	Borda ranking[b]	

[a]This option was introduced in the DynaRank system (Hillestad and Davis, 1998).

[b]A single-winner election method in which voters rank candidates in order of preference.

Link method is similar but even more stringent. It assesses the aggregate score to be the lowest of the contributing scores and assesses overall effectiveness as the lowest of the measure scores.[4] The third method (Weak Thresholds) is less draconian. Both measure-level scores and overall effectiveness are simply weighted sums. A contributing factor is scored zero if it does not reach its threshold value, but the aggregate score is the sum of the factors' scores (rather than zero). This method is suitable if the contributing measures are not individually critical but it seems important to impose thresholding.

These methods are effective heuristics that are well understood by decisionmakers. A tough commander or manager, for example, may consider a unit to have "failed inspection," even if the unit did rather well in many respects.

The other two aggregation methods (goals and rankings) are useful in certain cases, as discussed in Chapter Five.

Extensibility: Allowing Custom Aggregation Methods

In several of our applications of PAT, we have found it necessary to aggregate results in ways that do not lend themselves well to the built-in options. This can be done straightforwardly, using standard features of Excel and modest amounts of mathematics.

[4] This rule was introduced in Hillestad and Davis, 1998.

Hint (one that will be meaningful only to someone who is ready to actually use PAT): One approach when calculating an aggregation from a given level is (1) add a new measure at that level called "calculated score"; (2) define option values for that measure with an equation referring to other data (e.g., to the product of previous measures at the same level); (3) set the weights of the other measures to be very small but not zero (e.g., 0.0001) and the weight of the calculated score to be 1; (4) use any of the three core scoring methods in Table 2.1. The result will be that the aggregate score will be the calculated value, but the analyst will still see the values of the component factors when using PAT's drilldown feature as described in Chapter Three.

NOTE: When extending PAT's functionality by entering equations, users should ordinarily use "absolute references" (with $ signs) so that the formulas will be automatically adjusted if they change PAT's structure by, e.g., adding a column or row. Checking is important. Users should also avoid—or at least be very cautious about—using array formulas within PAT if further changes in structure are likely.

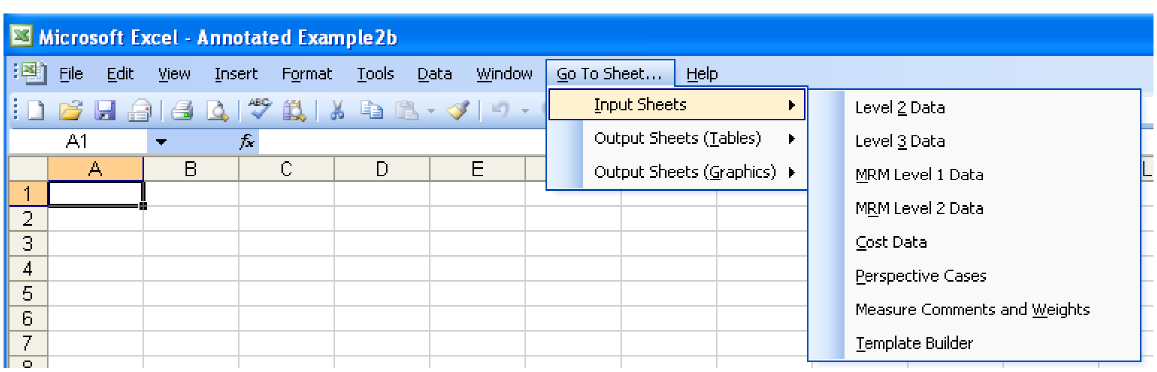
Navigation and Architecture: Inputs and Outputs

We now provide an overview of how one navigates within PAT, the inputs that must be provided, and the outputs it generates. Subsequent chapters will describe inputs and outputs in much more detail.

Architecture and Navigation

Since PAT is implemented in Excel, it uses a spreadsheet paradigm for entering data and generating familiar kinds of tables and charts. In basic terminology, a PAT file is an Excel "workbook" that contains multiple "worksheets." (In this report, we use the terms "worksheet" and "sheet" interchangeably.) The user navigates among worksheets in three ways: (1) by using the Go To Sheet menu item at the top of the program's window,[5] (2) by clicking tabs along the bottom of the program's window (the standard method in Excel); or (3) by clicking buttons that appear in some sheets (again, a standard method in Excel). The first option is often the easiest. Figure 2.5 shows where the menu is found (on any PAT sheet); Figure 2.6 shows tabs at the bottom of the Excel window; and Table 2.2 shows the menu of built-in worksheets.

Figure 2.5
Menu of Input and Output Sheets



[5] In Excel 2007, the Go To Sheet menu is accessed under the Other Add-Ins menu.

Figure 2.6
Tabs for Moving Among Sheets

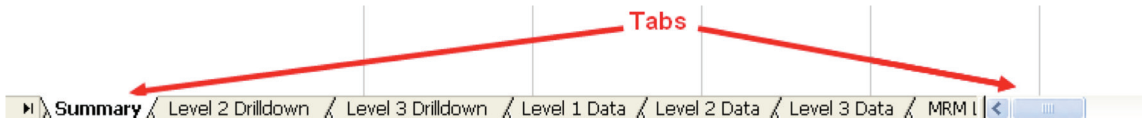


Table 2.2
PAT Output and Input Sheets

Output Sheets	Input Sheets
Tables (e.g., Scorecards)	Level 1 Data
Summary	Level 2 Data
Level 2 Drilldown	Level 3 Data
Level 3 Drilldown	MRM Level 1 Data
Selected Details	MRM Level 2 Data
Rankings Table	Cost Data
Graphics	Perspectives
Scatter Plot	*Template Builder*
Spider Charts	
Multimeasure Spider Charts	
Cost Charts	

Although convenient, the Go To Sheet menu omits custom sheets that the user may have added for extra data, specialized calculations, or notes. In contrast, all of the sheets have corresponding tabs along the bottom. The standard Excel way to navigate among sheets is by clicking those tabs. Table 2.3 shows the default left-to-right order of tabs, but users may have other tabs corresponding to application-specific worksheets and will in any case find it convenient to reorder the tabs by moving them around. Thus, the order in Table 2.3 may not apply. A *Notes* sheet is optional, something we suggest that the user add as a custom sheet for keeping track of changes and subtleties and for maintaining configuration control (i.e., assuring that collaborators are using the same version of PAT).

In a spreadsheet program such as PAT, "architecture" is largely indicated by the choice of worksheets and the relationships among them (e.g., *Level 2 Drilldown* provides more detail on some aspects of the results shown in the *Summary* sheet).

Inputs and Outputs

With this background, let us review schematically PAT's key outputs. This will provide a sense of what PAT does before we get into the details. Figure 2.7 is the schematic diagram of our topmost display, the *Summary* sheet.

Table 2.3
Default-Ordered Listing of Tabs for PAT Sheets

Welcome Screen
Summary
Level 2 Drilldown
Level 3 Drilldown
Scatter Plot
Spider Charts
Cost Charts
Rankings Table
Level 1 Data
Level 2 Data
Level 3 Data
MRM Level 1 Data
MRM Level 2 Data
Selected Details
Cost Data
Perspectives
Template Builder
Dropdown

Figure 2.7
Schematic of Summary Sheet

Measures	Measure 1	Measure 2	Measure 3		Total Cost: 2010-2015 ($M)	Effectiveness	Relative Cost Effectiveness
Investment Options	Detail	Detail	Detail	Detail	Detail		
Option A	G	Y	R		2561	0.5	1
Option B	LG	O	Y		2177	0.53	1.25
Option C	O	R	O		852	0.25	1.5

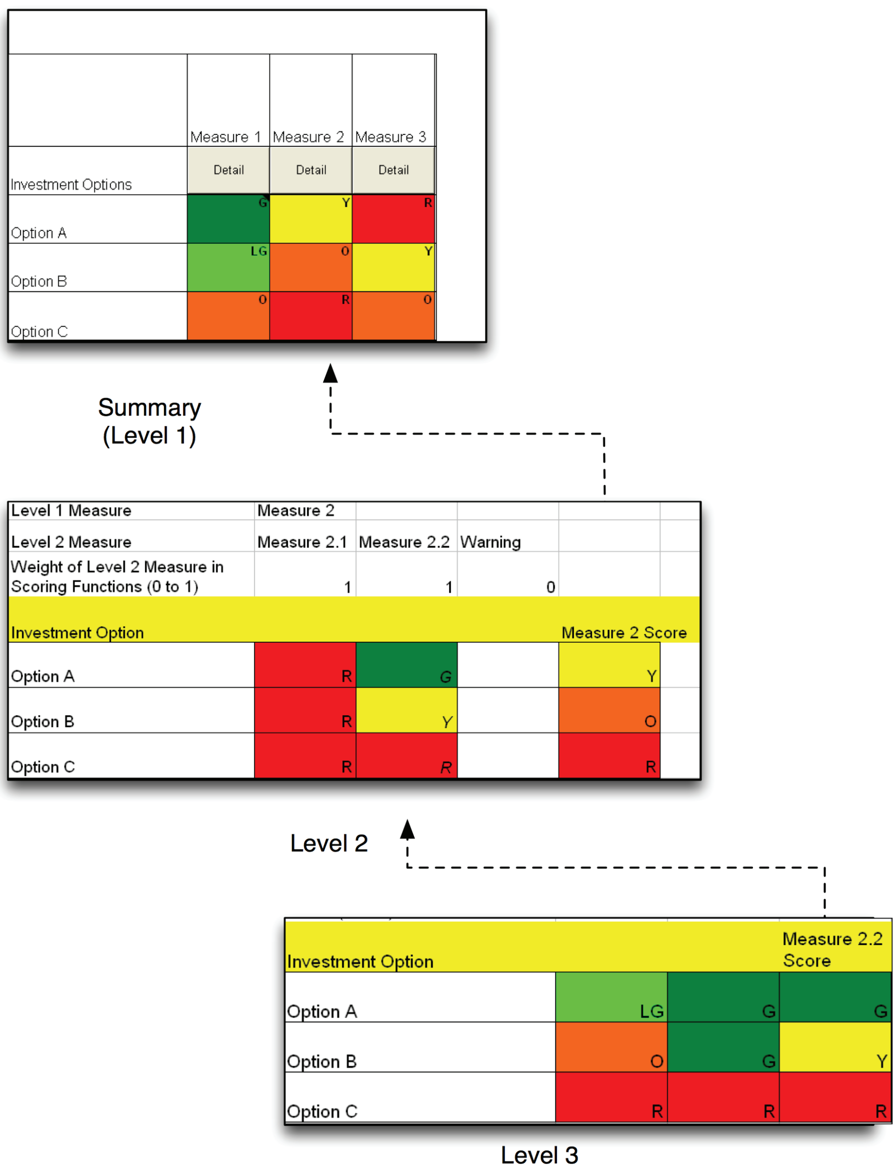
At the top of the sheet are some controls. At the bottom of the sheet is a translation from color-coding into numbers. In the main portion of the sheet, rows represent investment options. Each option is scored by different criteria or measures represented by the columns. The first block of assessments is the color-coded scorecard of Level 1 measure values (A, B, C). Moving rightward, blocks contain numeric values, such as of selected measures that the analyst wishes to highlight, cost data, and effectiveness and cost-effectiveness values. Ordinarily, the user will have only a portion of the *Summary* sheet visible (e.g., the scorecard portion).

The primary challenges in working with such high-level depictions are assuring that they frame the problem well, highlighting the right considerations, and assuring that the depictions reflect assessments based on solid analysis with a good audit trail. The analysis may be based on

information from capability models, structured subjective judgment sources, expert judgment based on detailed studies, or other sources.

Users should have the ability to understand why a given cell of the *Summary* sheet is red, rather than green (bad, rather than good) or where various numbers came from. This can be done to a significant extent within PAT by—for a particular measure—drilling down or zooming (we use the terms interchangeably) to sheets describing matters at Level 2 and Level 3. Figure 2.8 shows this schematically, suppressing all aspects of the sheets except the scorecards at Level 1, Level 2, and Level 3. In the example, the user drills down on Measure 2 of the Summary chart, discovering that it is based on two Level 2 measures. If he drills down

Figure 2.8
Schematic of Drilldown (Zoom)



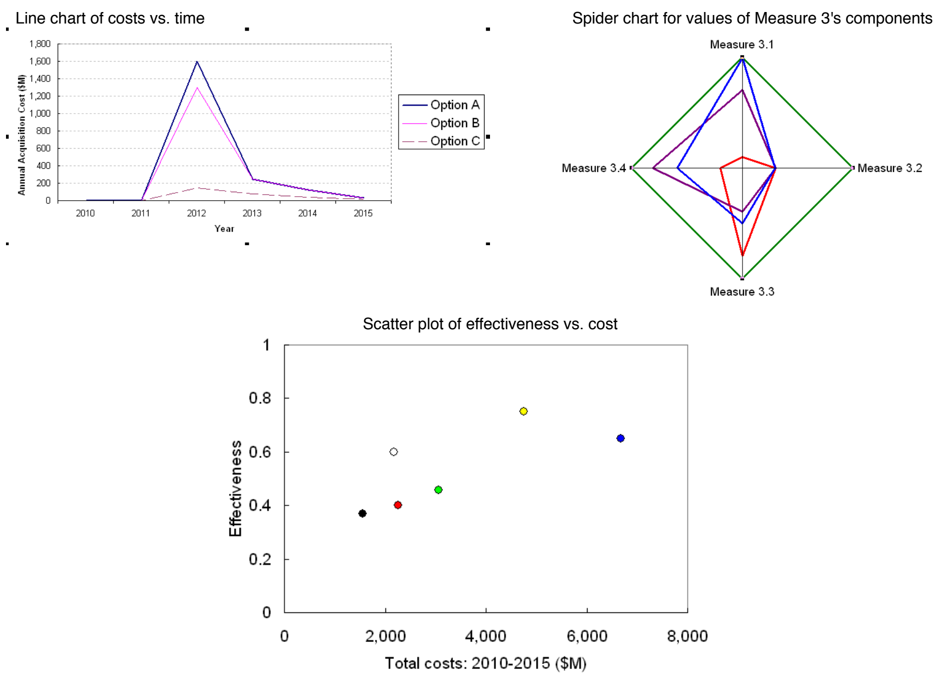
further, on the second of the two Level 2 measures, he finds that Measure 2 is based on calculations using three Level 3 measures. In most cases, this drilling down provides an adequate visual explanation of results. However, such is not always the case, and it may be necessary to study more analytically detailed results from capability models and the equations used to generate aggregations.

PAT also generates numerous graphics, which can be useful in the course of analysis and in the presentation of results. Figure 2.9 illustrates several types of built-in graphics: a line chart, a spider chart, and a scatter plot. Examples of each type of chart will be discussed in later chapters. Because a PAT file is an Excel spreadsheet, the user can also create and customize charts, using Excel's standard features.

With this quick overview, let us now turn to a more detailed discussion. Chapters Three and Four describe input and output sheets at a reference-manual level of detail. Chapter Five then provides detail on methodology, presenting equations and definitions for the most general cases treated by PAT. Chapter Six illustrates marginal analysis.

Readers who prefer to move directly into "doing" rather than reading may wish to use the QuickStart example in Appendix A.

Figure 2.9
Sample Output Displays from PAT



CHAPTER THREE

PAT Input Worksheets

This chapter describes each PAT input worksheet[1] and shows either a screen capture or a schematic of each. Names of the worksheets are in italics throughout the report, except in headings.

Template Builder

Users will ordinarily start their work with PAT by filling out the information in a tool called *Template Builder*. Here they will specify the structure of most sheets, such as the names of the Level 1, Level 2, and Level 3 measures; the names of the options; the time period; cost categories and expenditure items; and control variables. *Template Builder* then generates various other sheets appropriately, at which time the user specifies the option-dependent data and fine-tunes some of the controls. It is akin to filling out an outline and having the computer generate an entire book with chapter and section structure but no content. Despite the centrality of *Template Builder* for structuring PAT in practice, we defer its discussion until later in this chapter because serious users should first understand PAT's underlying architecture. This will improve intuition for what can and cannot be done and will help them diagnose problems that may arise because of erroneous data entries.

Level 1 Data

Figure 3.1 shows the *Level 1 Data* sheet for a simple case with only three measures. These data are reflected on the *Summary* sheet. The data to be inputted are (1) the names of the measures to be displayed,[2] (2) optional comments, and (3) the relative weights of the measures when calculating overall option effectiveness. As discussed in Chapter Four, if a user "mouses over" (i.e., passes the cursor over) a measure's name in the *Summary* sheet, a pop-up will show any comments (e.g., a cryptic definition) and weights. In this case the only comment is to define Measure 1 as "Effectiveness in Scenario 1; measured by outcome." After entering data, the user can click the Modify Summary button to have the data take effect.

[1] As with most modern tools, the distinction between input and output sheets is blurred, because some inputs can be changed in output sheets. This undercuts architectural clarity and can be confusing but is quite useful in practice.

[2] Once entered, these cannot be changed in *Level 1 Data* alone but can be changed using Find and Replace.

Figure 3.1
Level 1 Data

Modify Summary

Measure	Comment	Weight
Measure 1	Effectiveness in Scenario 1; measured by outcome	1.00
Measure 2		1.00
Measure 3		1.00

Although this is the official input sheet for Level 1, users will usually employ *Template Builder* to create the structured input and output sheets, and they will usually specify the weights of Level 1 measures in the *Summary* sheet (even though that is nominally an output sheet).

Level 2 Data

The values of Level 1 measures (i.e., summary measures) are determined by data at Levels 2 and 3. Figure 3.2 shows the *Level 2 Data* sheet for our simple case with three measures, each with two submeasures. That is, each Level 1 measure depends on two Level 2 measures.

Names of Measures and Options

The Level 1 measure names are entered as column headers precisely as shown (one row for the Level 1 measure's name; one row for each of the Level 2 measures' names, including items called "Warning"). The names of the investment options are entered as row headers. All such names must be consistent across workbook sheets. For example, the Level 1 measure names must agree with those in the *Level 1 Data* sheet.

Hint: Editing names, which is commonly important to improve intuitive clarity, is best done by using Excel's Find and Replace function (applying it to the workbook rather than to the current sheet), rather than attempting to type consistently across sheets.

Data on Option Effectiveness

The lower part of Figure 3.2 (below the yellow divider) is filled in with Level 2 data for each investment option and measure. Most of the data can be directly inputted at this level, but Measure 2.2's italicized values indicate that they are calculated from Level 3 information. If the analyst types over the italicized numbers, the calculated numbers will be regenerated in the next PAT run, overwriting the "corrections." Thus, any changes to Measure 2.2's data must be made at Level 3. Any entry in the Warning column for a particular option should be text, as in the example shown for Measure 1. Such warnings cause little flags to appear in cells of the *Summary* scorecard. They appear in pop-ups if the user mouses over the flags (see Chapter Four).

The data on the options may come from a capabilities model or other sources, including subjective judgment or detailed studies.

Parameters Specifying the Nature of Scoring and Aggregation

The rows at the top of Figure 3.2 (above the yellow divider) specify the control parameters needed to aggregate from Level 2 to Level 1. How and whether a given control parameter is actually used depends on the scoring and aggregation methods chosen, which will be discussed later. These parameter values can be left blank for Warning columns; PAT ignores any values that are entered.

Figure 3.2
Level 2 Data Sheet

Modify Summary										
Level 1 Measure	Measure 1	Measure 1	Measure 1	Measure 2	Measure 2	Measure 2	Measure 3	Measure 3	Measure 3	
Level 2 Measure	Measure 1.1	Measure 1.2	Warning	Measure 2.1	Measure 2.2	Warning	Measure 3.1	Measure 3.2	Warning	
Weight of Level 2 Measure in Scoring Functions (0 to 1)	1.00	1.00	0.00	1.00	1.00	0.00	1.00	1.00	0.00	1.00
High or Low Values Desired?	High	Low		High	High		High	High		High
Threshold Value	0.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Goal Value	10.00	0.00	0.00	1.00	1.00	0.00	10.00	10.00	0.00	1.00
Level 2 Measure Score for Threshold Value (0 to 1)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 2 Measure Score for Goal Value (0 to 1)	1.00	1.00	0.00	1.00	1.00	0.00	1.00	1.00	0.00	1.00
Investment Option										
Option A	10.00	2.00	Some believe that M1.1.'s value could be onlyl 3.	1.00	*0.80*		1.00	2.00		
Option B	8.00	4.00		0.60	*0.50*		4.00	7.00		
Option C	5.00	8.00		0.50	*0.00*		3.00	3.00		

The scoring and aggregation functions depend on parameters such as goal values. Four rows in the *Level 2 Data* sheet set those parameters:

- *Weight of Level 2 Measure in Scoring Functions (0 to 1).* The relative weights of the Level 2 measures when calculating the Level 1 scores (those used for the *Summary* sheet). A weight of zero means that the Level 2 measure is not considered. Thus, a Level 2 measure can be built in but then toggled on or off as appropriate.
- *High or Low Values Desired?* Either High or Low (capitalization matters). This row allows users to specify that for some measures (e.g., probability of failure), more is worse rather than better. If Low is chosen (e.g., as with Measure 1.2), scoring uses a variant of Figure 2.2. This choice of directionalities applies only at the lowest level of data entry; PAT rescales higher measures to be on a 0-to-1 scale, with 1 being better.

> *Hint:* This dictates care in naming. Lowest-level entries for various types of risk might be defined so that low numbers are good. Aggregations, however, because they will be rescaled by PAT, should be named something like "Confidence" or "Risk Mitigation" to avoid semantic confusion.

- *Threshold Value*. The threshold values described in Chapter Two for the Thresholds, Weakest Link, and Weak Thresholds scoring methods.
- *Goal Value*. The goal value used in all scoring functions except Rankings. Where high values are desired, the goal value cannot be lower than the threshold value. Where low values are desired, the goal value cannot be higher than the threshold value.

Effectiveness and cost-effectiveness calculations aggregate across measures and need to operate on a common scale. This is accomplished by setting two further parameters:

- *Level 2 Measure Score for Threshold Value (0 to 1)*. Scores assigned to Level 2 measures if their thresholds are just reached (for scoring methods that incorporate thresholds).
- *Level 2 Measure Score for Goal Value (0 to 1)*. Scores assigned if goal values are reached or exceeded. For scoring methods with thresholds, the effectiveness score for a value that falls between the threshold and the goal value is interpolated linearly (Figure 2.2). It is good practice to set this value to 1 for all measures.

Warning Comments

Each Level 1 measure may reflect a special Level 2 measure called Warning. The data in the Warning columns should be text. If a given cell has a warning, the *Summary* display will have a small flag in the top right corner of the corresponding cell. Mousing over that cell will bring the warning message up. This mechanism is a convenient way of flagging results that depend on reasonable but worrisome assumptions. In a defense-planning analysis, such a flag might be "Assumes at least one week's actionable strategic warning."

The Modify Summary Button

After making changes in data at any level, the user should click the Modify Summary button (top left) or go to the *Summary* sheet and select Update Summary to have the changes take effect.

Cautionary: If *any* Level 2 measure for a particular Level 1 measure is calculated from Level 3 data, any Level 2 measures inputted directly should also be given raw values from 0 to 1. PAT reports the calculation from Level 3 using the 0-to-1 range, and visual explanations such as the *Level 2 Drilldown* sheet become non-intuitive if the various Level 2 measures are on different scales.

Hint: Entering data with decimal points can be more tedious and prone to error than entering whole-integer numbers. The user can enter the option-specific data with whole integers and then scale them down by (1) entering 0.1 in a cell outside the array, (2) cutting, (3) selecting the range of cells to be scaled, and (4) selecting Edit/Paste Special/Multiply from the Excel menu. If that menu option does not appear, use Tools/Add-Ins to activate some optional features of Excel. Be sure not to leave any stray items in the sheet (e.g., the 0.1).

Level 3 Data

Figure 3.3 shows the *Level 3 Data* sheet for our simple example in which only Measure 2 has Level 3 data (Measures 2.2.1 and 2.2.2). The sheet is very similar to that for Level 2. Although small in this example, it is often quite large in applications—it may have tens of columns.

Figure 3.3
Level 3 Data Sheet

☑ Failure scores zero (not -1) Modify Level 2 Data Sheet		
Level 1 Measure	Measure 2	Measure 2
Level 2 Measure	Measure 2.2	Measure 2.2
Level 3 Measure	Measure 2.2.1	Measure 2.2.2
Scoring Method (Enter once for each Level 2 Measure: Goals, Thresholds, Weak Thresholds, Weakest Link)	Thresholds	Thresholds
Weight of Level 3 Measure in Scoring Functions (0 to 1)	1	1
High or Low Values Desired?	High	High
Threshold Value	5	5
Goal Value	10	10
Level 3 Measure Score for Threshold Value (0 to 1)	0	0
Level 3 Measure Score for Goal Value (0 to 1)	1	1
Investment Option		
Option A	8	10
Option B	6	9
Option C	4	2

At the top left of the sheet is a button called Modify Level 2 Data Sheet (used to recalculate the values of Level 2 information generated from Level 3). The tiny box with a checkmark should remain checked.[3]

Some Level 3 data can be changed in output sheets, but the user should be sure to click appropriate buttons, such as Modify Level 2 Data Sheet, so that the changes will take effect. Arguably, this functionality (of changing inputs in an output sheet) should be avoided because of the potential for confusion.

MRM Level 1 and Level 2 Data

The *MRM Level 1 Data* and *MRM Level 2 Data* sheets allow the user to have a low-detail mechanism for inputting data, so that fewer changes are necessary when doing sensitivity analysis or more general exploratory analysis. This can be quite useful, but the user should remember that these data sheets are distinct from the nominal data provided in the *Level 2 Data* and *Level 3 Data* sheets. The analyst must maintain such consistency as is needed.

This MRM functionality is valuable to the analyst who wishes to work at a low level of resolution until everything is "making sense," at which point, more detail and more care in specifying data may be appropriate. This is standard in good top-down analysis and in soft-

[3] This option affects certain displays if a measure's raw value is below its threshold. It is best ignored. However, a checked box means that a measure with a score well below its threshold will get the same score (0) as it would have if it had just reached the threshold. An unchecked box assigns a score of –1 in the former case.

ware engineering. Without the MRM option, making even what seem like simple changes may require entering many low-level data values. That is both tedious and an invitation to error.

More important ultimately (but more controversial among analysts who like to argue about such things) is the fact that the MRM design encourages thinking top-down and eliminates the requirement to enter what may be spurious detail. In many instances, the information available for the assessment of a particular measure is inherently of low resolution. For example, if expert consultants with years of managerial experience are asked to judge the risk of some alternative programs, they may be able to do so quickly and well. However, if they are asked to break down their judgments—listing components and subcomponents of risk, and then estimating values and probabilities of those risks individually—the quality of the assessment may worsen rather than improve. The reasons for this are many. One reason is that *many* things can go wrong, and experts often smell the potential for problems without being able to predict which particular problems will arise. If they are forced to itemize, they may omit some of the possibilities. Another theoretical problem is that the errors made in low-level (high-resolution) subjective estimates do not propagate upward nicely. An aggregate-level assessment may be more accurate than the result of calculations based on many low-level assessments.

For brevity, we do not show examples of the *MRM Level 1* and *MRM Level 2 Data* sheets here. The former is trivial—one merely inputs the "answers" that are to be displayed in the *Summary* display. The latter looks like and operates like the *Level 2 Data* sheet.

Hint: Two usage scenarios are worth mentioning. In the first, the analyst is thinking top-down and doesn't want to specify details. Like a designer or system engineer, he leaves "markers" or "stubs" by entering the names of Level 2 and Level 3 measures, but instead of filling in the detail, he creates a separate *MRM Level 2 Data* sheet and fills that out. He does initial work at that level (invoking that data sheet in the *Summary* sheet's Multi-Resolution Modeling menu). When the time comes, he reverts to using the data sheet with both Level 2 and Level 3 data and fills in details as needed.

In the second scenario, the analyst begins bottom-up, working with Level 3 detail. At some point, he finds it necessary to be more agile and to think at a higher level—perhaps when exploring uncertainty or responding to aggregate-level "What if . . .?" questions. He copies his previous Level 2 information from the *Level 2 Drilldown* sheet into the *MRM Level 2 Data* sheet, invokes MRM Level 2 data with the Multi-Resolution Modeling menu, and proceeds. When he is done, he may revert to the detailed analysis. He may find, however, that some Level-3-to-Level-2 calculations were spurious because of hopelessly ambiguous data or uncertain phenomena. Dispensing with such spurious (and pretentious) detail would then be desirable. In other cases, the detail is essential.

Using MRM Level 1 data is unusual but can be useful for experimenting with story lines and displays. Using it will specify the colors that appear in the *Summary* scorecard.

Some of the items in MRM data sheets can be changed in output sheets, but the user should then click appropriate buttons to trigger updating. It is best to make the changes in the input sheet and click the appropriate Modify button. And, as mentioned earlier, it is arguably dangerous to enter inputs in output sheets, because of the potential for confusion.

Cost Data

Establishing Cost Structure

PAT allows the user considerable latitude in representing cost information about various options. The choices include:

- Time frame (e.g., six-year, 20-year, or forever costs)
- Categories of cost (e.g., R&D, acquisition, O&S)
- Items (the classes of investment items, such as hardware and software, or ships, aircraft, and tanks)
- Discount rate (representation of inflation, or of inflation plus the real discount rate as needed in present-value calculations).

Figure 3.4 illustrates the format of the *Cost Data* sheet. For compactness, this example has only a three-year time frame and two types of investment items. A more realistic example would require scores of columns and rows.

To specify cost structure and data starting with a blank *Cost Data* sheet, the user should specify one block of columns for each cost category. Each block should have the same number of columns with the same range of years. One block of rows should be entered for each option. Each block should have the same set of rows representing different cost items over the same time period. Each block of columns and rows should be separated from the next by one column or row, respectively.

The analyst is responsible for entering appropriate data such as current-year (also called then-year) or real (inflation-corrected) costs. For present-value calculations of cost-effectiveness, a real discount factor can be specified here or in the *Summary* sheet. That will override data in the data sheet when making calculations for the *Summary* sheet. That is, if the *Cost Data* sheet has constant-dollar entries, but the *Summary* sheet specifies a discount rate of 3 percent, the dollar values listed in the *Summary* sheet and used for cost-effectiveness calculations will be in present-value terms assuming that the value of money is 3 percent on top of inflation.

An Easier Approach to Structuring Cost Data

It can be tedious to set up the data structure in the *Cost Data* sheet, so the recommended approach is to specify the structure in *Template Builder*, which will then fill out the sheet except for the costs of the options themselves. Simplification is also desirable in many cases, as shown below.

Customized Cost Calculations

It will sometimes be desirable to customize cost data or cost calculations in ways not anticipated by PAT's built-in options or to juxtapose calculations for different assumptions (e.g., different rates of inflation or discount rate, or different horizons short of infinity for calculating present values). That can be accomplished in a separate worksheet that may draw from the *Cost Data* sheet (Davis et al., 2008). Results can be displayed in the *Summary* sheet, using its custom cost columns or in the worksheet itself.

Figure 3.4
Cost Data Sheet

Modify Summary	Discount Rate (Rel to First Year)			0																
R&D Cost ($M)							Acquisition Cost ($M)							Operations Cost ($M)						
Option A	2,010	2,011	2,012	2,013	2,014	2,015	Option A	2,010	2,011	2,012	2,013	2,014	2,015	Option A	2,010	2,011	2,012	2,013	2,014	2,015
Hardware	90	28	0	0	0	0	Hardware	0	0	1,500	200	100	20	Hardware	0	0	0	10	120	120
Software	30	28	28	10	4	3	Software	0	0	100	50	20	10	Software	0	0	0	30	30	30
R&D Cost ($M)							Acquisition Cost ($M)							Operations Cost ($M)						
Option B	2,010	2,011	2,012	2,013	2,014	2,015	Option B	2,010	2,011	2,012	2,013	2,014	2,015	Option B	2,010	2,011	2,012	2,013	2,014	2,015
Hardware	100	30	0	0	0	0	Hardware	0	0	1,200	200	100	20	Hardware	0	0	0	10	100	100
Software	30	30	30	10	4	3	Software	0	0	100	50	20	10	Software	0	0	0	10	10	10
R&D Cost ($M)							Acquisition Cost ($M)							Operations Cost ($M)						
Option C	2,010	2,011	2,012	2,013	2,014	2,015	Option C	2,010	2,011	2,012	2,013	2,014	2,015	Option C	2,010	2,011	2,012	2,013	2,014	2,015
Hardware	70	20	0	0	0	0	Hardware	0	0	100	50	30	10	Hardware	30	35	40	45	50	55
Software	30	20	20	10	4	3	Software	0	0	50	30	10	5	Software	10	15	20	25	30	35

Simplifications

It is often desirable for the analyst to take shortcuts in dealing with costs, especially early in a project. He may wish to think simply in terms of total costs—over all categories and over all the years of interest. Further, when he conducts sensitivity analyses, he may wish to change only one cost number per option.

PAT has no "multiresolution data entry" option for costing, but the simplification is easy. Either in the *Cost Data* sheet directly or via *Template Builder*, the analyst can specify having only a single cost category such as "Total Cost ($M)" and the only investment item may be "Stuff."

> *Hint:* An additional worksheet can be created to enter detailed cost information, for use when needed. Later, the information might be entered into *Cost Data* with a revised format.

The level of detail used, then, is very much up to the analyst and can be changed in the course of a study.

Perspectives

The Basic Concept of Perspectives

As discussed in Chapters One and Two, an important feature of PAT is its ability to show how cost-effectiveness landscapes vary as a function of strategic perspective. A perspective is represented by the different sets of choices used in scoring and aggregation. Figure 3.5 shows the *Perspectives* sheet for our continuing example. It illustrates the format for entering alternative perspectives, starting with a blank sheet (or one that already includes a default perspective).

Each perspective is a block of rows. Each block has a header row with the name of the perspective; the rest of the block has precisely the same structure as the top portion of a *Level 2 Data* sheet. That is, it includes the part that specifies the weighting factors, thresholds, goals, and so on for each Level 2 measure. The blocks contain no information about the options. The blocks corresponding to perspectives are juxtaposed (i.e., there is no space between them). The weights of the Level 2 measures appear in the header line. In the example, the weights appear in every relevant column, but it is permissible to have them appear only once per group.

The user can create a full set of perspectives directly on a previously blank *Perspectives* sheet by adhering to the syntax of the example. It is relatively easy to make data-entry mistakes, however.

Once changes are made in a given perspective, they will take effect only if one of them is chosen anew in the *Summary* sheet as the current perspective. If a change is made to the current perspective in the *Perspectives* sheet, the user should select a different current perspective in the *Summary* sheet's menu and then change again the perspective in question. That will refresh the current perspective appropriately.

Currently, perspectives can be defined only with respect to Level 2 data, except through the method of extended perspectives discussed below.

Figure 3.5
Illustrative Perspectives Cases

Default	1	1	1	1	1	1	
Level 1 Measure	Measure 1	Measure 1	Measure 1	Measure 2	Measure 2	Measure 2	Measu
Level 2 Measure	Measure 1.1	Measure 1.2	Warning	Measure 2.1	Measure 2.2	Warning	Measu
Weight of Level 2 Measure in Scoring Functions (0 to 1)	1	1		1	1		
High or Low Values Desired?	High	Low		High	High		High
Threshold Value	0	0		0	0		
Goal Value	1	1		1	1		
Level 2 Measure Score for Threshold Value (0 to 1)	0	0		0	0		
Level 2 Measure Score for Goal Value (0 to 1)	1	1		1	1		
Baseline (1,1,1)	1	1	1	1	1	1	
Level 1 Measure	Measure 1	Measure 1	Measure 1	Measure 2	Measure 2	Measure 2	Measu
Level 2 Measure	Measure 1.1	Measure 1.2	Warning	Measure 2.1	Measure 2.2	Warning	Measu
Weight of Level 2 Measure in Scoring Functions (0 to 1)	1	1	0	1	1	0	
High or Low Values Desired?	High	Low		High	High		High
Threshold Value	0	10	0	0	0	0	
Goal Value	10	0	0	1	1	0	
Level 2 Measure Score for Threshold Value (0 to 1)	0	0	0	0	0	0	
Level 2 Measure Score for Goal Value (0 to 1)	1	1	0	1	1	0	
Measure 1 Emphasis (2,1,.5)	2	2	2	1	1	1	
Level 1 Measure	Measure 1	Measure 1	Measure 1	Measure 2	Measure 2	Measure 2	Measu
Level 2 Measure	Measure 1.1	Measure 1.2	Warning	Measure 2.1	Measure 2.2	Warning	Measu
Weight of Level 2 Measure in Scoring Functions (0 to 1)	1	1	0	1	1	0	
High or Low Values Desired?	High	Low		High	High		High
Threshold Value	0	10	0	0	0	0	
Goal Value	10	0	0	1	1	0	
Level 2 Measure Score for Threshold Value (0 to 1)	0	0	0	0	0	0	
Level 2 Measure Score for Goal Value (0 to 1)	1	1	0	1	1	0	
Weakest Link (2,1,.5)	2	2	2	1	1	1	
Level 1 Measure	Measure 1	Measure 1	Measure 1	Measure 2	Measure 2	Measure 2	Measu
Level 2 Measure	Measure 1.1	Measure 1.2	Warning	Measure 2.1	Measure 2.2	Warning	Measu
Weight of Level 2 Measure in Scoring Functions (0 to 1)	1	1	0	1	1	0	
High or Low Values Desired?	High	Low		High	High		High
Threshold Value	0	10	0	0	0	0	
Goal Value	10	0	0	1	1	0	
Level 2 Measure Score for Threshold Value (0 to 1)	0	0	0	0	0	0	
Level 2 Measure Score for Goal Value (0 to 1)	1	1	0	1	1	0	

Easier Ways to Create and Store Perspectives

In practice, the easiest way to create perspectives may be by working with the measure weights and the Current Perspective menu in the *Summary* sheet. The procedure (also described in Chapter Four) is as follows:

- In the *Summary* sheet, change Level 1 measure weights to those appropriate for the new perspective. If desired, also change the scoring method used (e.g., Weakest Link instead of Thresholds). If desired (this is more unusual), go to the relevant *Level 2 Data* sheet (the normal one or the *MRM* sheet) and change any of the control parameters that control scoring and aggregation, click Modify Summary, and then return to the *Summary* sheet.
- Go to the Current Perspective menu (top left) and select Generate New Perspective.
- When prompted, fill in the name of the new perspective and hit return.
- PAT will automatically copy and paste appropriate data into a new block of the *Perspectives* data sheet.

Figure 3.6 illustrates the Perspectives menu from the *Summary* sheet. It indicates the presence of four perspectives (Default, Baseline, Measure 1 Emphasis, and Weakest Link), just as shown in Figure 3.5. In this example, we included the weights as part of the titles so that we could remember what they represented.

Some other rules are necessary to use this approach effectively:

1. After using the Current Perspective menu, either to generate a new perspective or to change perspectives, the user will be prompted by PAT (Figure 3.7) and given the opportunity to enter a perspective name. If the current settings (weights, etc., have been reset for a new perspective, enter that name. If they have been reset to change the definition of an existing perspective, type the old perspective's name and, when prompted again, choose Yes. Otherwise hit OK, without entering a name. This query box appears routinely when closing PAT, even if no changes in perspective have been made. The usual response is OK.
2. If errors are made and problems arise, corrections to existing perspectives can usually be made by editing the *Perspectives* data sheet. In some cases, however, there will be an error message about inconsistencies between the *Level 2 Data* sheet and the *Perspectives* sheet. It is often easiest to delete everything on the *Perspectives* data sheet and recreate the perspectives from scratch. That avoids tedious trouble-shooting.

Figure 3.6
Using the Summary Sheet's Perspectives Menu

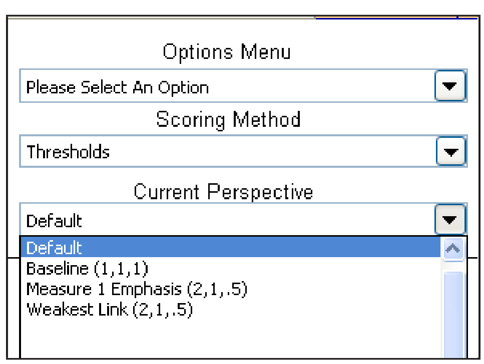
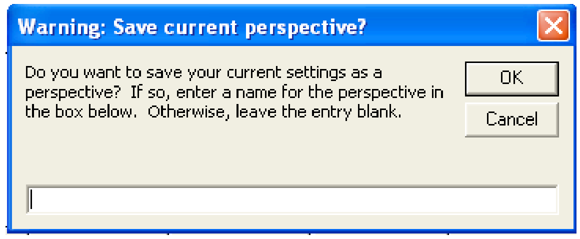


Figure 3.7
Query About Saving or Creating a New Perspective



Extended Perspectives

An analyst getting into the spirit of exploring the consequences of alternative perspectives may wish for a change of perspectives that would have more consequences than are allowed by the built-in features of PAT, which apply only to changes at Level 2 relating to weights, goals, thresholds, scoring scheme, and aggregation method.

In particular, it is sometimes logical to associate a perspective with changes in the assessments of some or all options, not just the weight of those measures. For example, a conservative perspective might evaluate risks to be much higher than an optimistic perspective would. Or, one perspective might logically weigh Level 3 data differently than another perspective would.

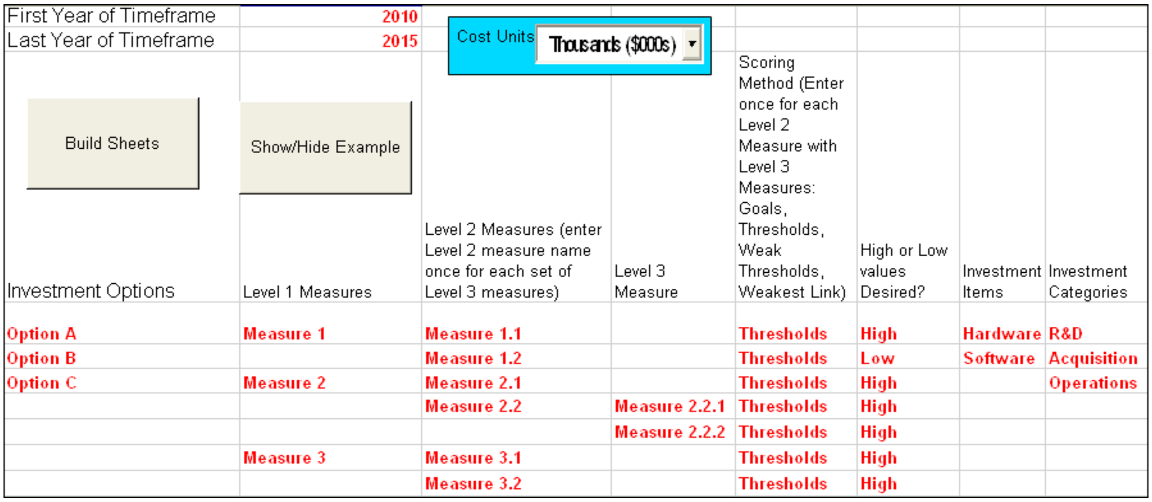
Although this is not enabled by PAT's built-in machinery, extended perspectives can be defined by someone skilled in using Excel. This might involve, for example, appending some multipliers to the data elements that would be dependent on the extended perspective, with an interface to those multipliers' values on a custom sheet. When changing an extended perspective, the analyst should remember to change the multipliers' values. A somewhat safer approach would be to build a macro that would be used each time PAT ran and, depending on the extended perspective chosen, would set the parameter values.

Template Builder

We have mentioned *Template Builder* repeatedly throughout this chapter. Figure 3.8 illustrates it for the very simple example used in most of this report. The example is much smaller and less busy than a real application will be. The inputs are in red. Although it is conceptually simple, some rules must be followed to fill it in correctly:

1. Filling in the Timeframe (top left) is simple, as is picking the cost units from the menu item.
2. The block of items in the first column, Investment Options, must have the options spelled exactly as they are to appear on displays. This list is unrelated to anything else on the sheet. That is, Option A has nothing to do with Measure 1, even though it is adjacent to it.
3. The Level 1, Level 2, and Level 3 measures are entered in the syntax shown in the example, which means that their relative positioning matters. Thus, Measure 1.1 and Measure 1.2 appear in cells adjacent to the cell showing Measure 1, with the first of them being right beside it. Similarly, for the one example of a Level 3 measure (Measure 2.2.1), the name must go immediately to the right of Measure 2.2. One of the most common mistakes in using PAT is getting these alignments wrong.

Figure 3.8
Template Builder for a Simple Example



First Year of Timeframe	2010	Cost Units: Thousands ($000s)					
Last Year of Timeframe	2015						
Build Sheets	Show/Hide Example						
Investment Options	Level 1 Measures	Level 2 Measures (enter Level 2 measure name once for each set of Level 3 measures)	Level 3 Measure	Scoring Method (Enter once for each Level 2 Measure with Level 3 Measures: Goals, Thresholds, Weak Thresholds, Weakest Link)	High or Low values Desired?	Investment Items	Investment Categories
Option A	Measure 1	Measure 1.1		Thresholds	High	Hardware	R&D
Option B		Measure 1.2		Thresholds	Low	Software	Acquisition
Option C	Measure 2	Measure 2.1		Thresholds	High		Operations
		Measure 2.2	Measure 2.2.1	Thresholds	High		
			Measure 2.2.2	Thresholds	High		
	Measure 3	Measure 3.1		Thresholds	High		
		Measure 3.2		Thresholds	High		

4. The Scoring Method and High or Low Values Desired columns can be filled in straightforwardly, using the following choices (capitalization matters):
   — Scoring Method: Thresholds, Weakest Link, Weak Thresholds, Rankings
   — Goals
   — High or Low Values Desired?: High, Low

   If the user changes these settings while using PAT, by going into the *Level 2 Data* or *Level 3 Data* sheet, for example, *Template Builder's* data will be rendered obsolete. That may be good or bad. *Template Builder's* data could be regarded as a default to which one could return, or one might be worried that rerunning *Template Builder* for other reasons would introduce errors. Caution is necessary.
5. The names entered under Cost Categories have nothing to do with the rest of the sheet.
6. The names entered under Investment Items have nothing to do with the rest of the sheet.
7. The combination of Cost Categories and Investment Items dictates the structure of the *Cost Data* sheet.

The Build Sheets command causes PAT to generate structures in numerous input and output sheets. The user will be prompted by a sequence of query messages that ask whether, in rebuilding, he wishes to preserve option-specific data already in the *Level 2* and *Level 3 Data* sheets, the *Perspectives* data sheet, and the *Cost Data* sheet. In many cases, saying Yes will save a great deal of time and trouble because data entry is time-consuming and prone to errors. Saying Yes is appropriate if, for example, the purpose of the rebuilding is to change the names of some measures or options, or to add some additional measures or options. In the first case (name-changing), the resulting data sheets will have "holes" wherever newly named options or measures appear. In the second case (adding new measures or options), the same will be true. Obviously, data cannot be retained if they do not exist.

Hint: If the user has made substantial changes in the data structure, or if errors have appeared that troubleshooting has not resolved, it may be better to rebuild entirely (saying No rather than Yes to retaining data), even though this will mean more data entry. Errors often are the result of subtle misalignments or typos (including extra spaces), which can be erased with a fresh rebuilding. After the new sheets are generated, the user may use Copy and Paste to move data in the old workbook to the new one, being careful to paste in the right place. A common error is pasting into what appears to be the top left corner only to discover that scrolling had displaced the columns so that the pasting was actually onto interior columns.

The Show/Hide button can be used to toggle on or off some in-sheet examples and instructions.

After *Template Builder* is run, the various input and output sheets will have a good deal of structure built in. This does *not* include option-specific data (unless they are retained from the previous version of PAT), and it does *not* include the setting of control variables at Levels 2 and 3, such as thresholds, goals, score at threshold, and score at goal. It also does not include specifying measure weights at any level. In some cases, PAT will build in default values (e.g., values of 1 for all measure weights and a value of 1 for the score associated with raw values at or exceeding a measure's goal). However, those may not be what is intended.

The bottom line here is that even with *Template Builder*, data-entry requirements can be considerable and should be undertaken methodically and with proofreading, because low-level entry errors may go undetected. In the vast majority of cases in which the authors have encountered errors in PAT over the past year or two, the problems originated in data entry and were not problems with PAT itself. A few additional problems had to do with misunderstandings. Few involved bugs, although bugs undoubtedly remain—especially for the least-exercised aspects of PAT functionality.

CHAPTER FOUR

PAT Output Worksheets

Summary Sheet

Structure of the Summary Sheet

The *Summary* sheet is the main output of PAT. We showed its schematic form in Figure 2.7, but Figure 4.1 shows a screenshot of the actual *Summary* sheet. Numerous columns have been hidden (see gray bars) so that the portions could be juxtaposed. Ordinarily, users work with only a portion of the sheet at a time, but it is convenient to have much information on the top-level sheet.

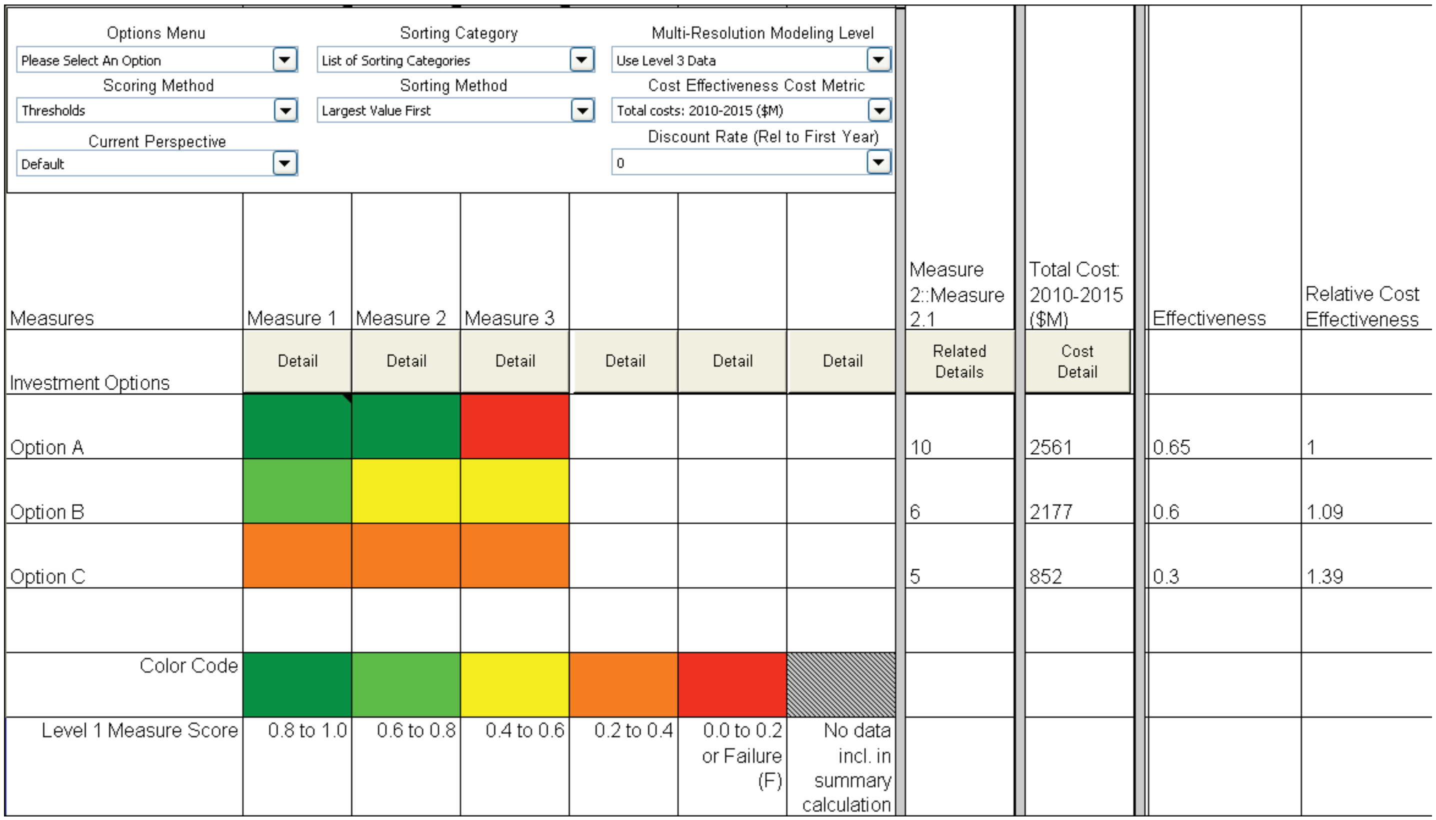
The *Summary* sheet's control panels provide a great deal of flexibility. All employ drop-down menus, the first of which is the Options menu (see Figure 4.2).

The Options menu is especially important for setting a number of user preferences. Some items are self-evident; some are less so.

1. *Update Summary Sheet.* The user should update the displays after changing data. This is the command to select when the user is in the *Summary*; some equivalent buttons exist in other sheets.
2. *Show/Hide Weights.* Having the weights of the various Level 1 measures shown can be toggled on or off. The weights are used in the calculation of effectiveness and cost-effectiveness.
3. *Change Color Scheme.* As shown in Figure 4.3, PAT provides four different color schemes for the scoreboards: the standard five-color style, a style with letters added to indicate the colors, a style with alternative colors, and a gray-scale style. The user can rotate through the set of styles by repetitively selecting Change Color Scheme.[1] Adding letters (top right) is valuable for people who are color-blind. Gray scale is sometimes seen as less dramatic.
4. *Update Menus.* In some instances, the user should update menus. For example, if the content of the *Perspectives Cases* sheet has been deleted to define fresh perspectives, the menu will continue to show the old ones until it is refreshed.
5. *Generate New Perspective.* This option will copy current settings to the *Perspectives* sheet with whatever name is specified in the query box that arises after the option is chosen.
6. *Update Perspective.* This option replaces data in the *Perspectives* sheet with data being used in the currently operative perspective (whether set in the *Summary* sheet or elsewhere).

[1] Further tuning of colors and patterns is possible using Excel's built-in capabilities, but doing so is tedious and, in our experience, unrewarding, because of Excel's limited palette. To obtain the colors intended, it may be necessary to recalibrate one's printer or computer.

Figure 4.1
Illustrative Summary Sheet



Options Menu: Please Select An Option
Scoring Method: Thresholds
Current Perspective: Default
Sorting Category: List of Sorting Categories
Sorting Method: Largest Value First
Multi-Resolution Modeling Level: Use Level 3 Data
Cost Effectiveness Cost Metric: Total costs: 2010-2015 ($M)
Discount Rate (Rel to First Year): 0

Measures	Measure 1	Measure 2	Measure 3				Measure 2::Measure 2.1	Total Cost: 2010-2015 ($M)	Effectiveness	Relative Cost Effectiveness
Investment Options	Detail	Detail	Detail	Detail	Detail	Detail	Related Details	Cost Detail		
Option A							10	2561	0.65	1
Option B							6	2177	0.6	1.09
Option C							5	852	0.3	1.39
Color Code										
Level 1 Measure Score	0.8 to 1.0	0.6 to 0.8	0.4 to 0.6	0.2 to 0.4	0.0 to 0.2 or Failure (F)	No data incl. in summary calculation				

Figure 4.2
Options Menu of Summary Sheet

- Update Summary Sheet
- Show/Hide Weights
- Change Color Scheme
- Update Menus
- Generate New Perspective
- Update Perspective
- Delete Perspective
- Add/Remove Failure Markers

Figure 4.3
Alternative Color Schemes for Scorecards

7. *Delete Perspective.* This option brings up a query box in which the user can specify deletion of any perspective other than the current one.
8. *Add/Remove Failure Markers.* This is an option to show (F) in cells for which the score falls below a threshold.

Continuing with the other control panels of Figure 4.1, sorting is controlled by two menus—one specifying the criterion for sorting, i.e., the choice of column (Figure 4.4) and one specifying whether the sorting will be in ascending or descending order (Figure 4.5). The choices of the former menu change with usage but include all of the *Summary* sheet columns (including effectiveness and relative cost-effectiveness), the various cost columns, and any Selected Measure columns that may have been added (the columns with buttons called Related Details).

Figure 4.4
Sorting-Categories Menu of Summary Sheet (Example-Specific)

Measure 1
Measure 2
Measure 3
Total Cost: 2010-2015 ($M)
R&D Cost: 2010-2015 ($M)
Acquisition Cost: 2010-2015 ($M)
O&S Cost: 2010-2015 ($M)
Effectiveness
Relative Cost Effectiveness

Figure 4.5
Sorting-Method Menu of Summary Sheet

Largest value first
Smallest value first

As discussed in Chapter Three, the user can, at any given time, choose to work with any of several versions of his data sheet. This is the MRM feature for which the choices are (Figure 4.6) entering data at Levels 2 and 3 (referred to as Use Level 3 Data), entering data at Level 2, or entering data at Level 1.

The user controls the scoring method (actually the method of aggregation), which sometimes has substantial effects. The choices available from the related menu (Figure 4.7) are those discussed in Chapter Three. The Thresholds method is the default choice. If no change is made to default thresholds and goals, the familiar method of linear weighted sums is used.

Figure 4.6
MRM Menu of Summary Sheet

Use Level 3 Data
Use MRM Level 2 Data
Use MRM Level 1 Data

Figure 4.7
Scoring-Method Menu of Summary Sheet

Goals
Thresholds
Rankings
Weakest Link
Weak Thresholds

Current perspective can be changed at any time, generating a recalculation of results, by using the corresponding menu (Figure 4.8). The entries in the menu are based on the perspectives the user has defined so far. The names in Figure 4.8 illustrate using shorthand names to remind the user of what a particular perspective means. In Baseline, for example, the weights of the three measures of our continuing example are all 1, whereas they are different in the next two perspectives. The last perspective changes both the emphasis (via weights) and the scoring/aggregation scheme.

The final control menu (Figure 4.9) allows the user to specify the discount rate, which is assumed to be between 0 and 0.1, corresponding to 0 to 10 percent. If *Cost Data* sheet items are in constant (inflation-adjusted) dollars, this menu item should be seen as the "real" discount rate, the earning power of money above the inflation rate. If *Cost Data* sheet items are in current dollars, the menu item should be seen as the sum of the inflation rate and the discount rate to be assumed in *Summary* sheet calculations.

We recommend that users specify the basic structure of their sheets by using *Template Builder*, as discussed at the end of Chapter Three. Most of the *Summary* sheet's columns will then be generated with appropriate headers and values when PAT is first run (by selecting Update Summary from the Options menu). If the user wishes to add or delete columns or options, it is usually best to do that in *Template Builder* and rebuild the sheets. However, changes can also be made as follows (with the disadvantage that they will not be reflected in the *Template Builder* sheet).

Figure 4.8
Current-Perspective Menu of Summary Sheet (Example-Specific)

Default
Baseline (1,1,1)
Measure 1 Emphasis (2,1,0.5)
Weakest Link (2,1,0.5)

Figure 4.9
Discount-Rate Menu (Summary Sheet)

0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10

Structuring Rows and Columns with Template Builder

Looking back to Figure 4.1 and ignoring the control panels at the top and the mapping of colors at the bottom, from left to right, for each investment option there are four blocks of output data, the dimensions of which are hard-wired in PAT:

- Up to 12 columns in a scorecard showing results for Level 1 measures.
- Up to four columns displaying numeric data (e.g., for selected measures from Level 2).
- Up to nine columns displaying cost data.
- Up to two additional columns presenting the effectiveness and relative cost-effectiveness of the investment options.

Adding or Deleting a Column

The user can add any Level 1 measure that has been introduced in the data sheets to the *Summary* scorecard simply by typing the measure's precise name in Row 1 for any of the columns set aside for the scorecard—nominally, columns B through M (the scorecard's "range"), but in any case, columns with Detail buttons. To delete any column from the scorecard, the user may erase the name in the header and select Update Summary from the Options menu.

Adding a Numeric Column of Level 2 Information

The user may wish to elevate the visibility of a particular Level 2 measure by including its numerical values in the *Summary* sheet, using the next block of columns indicated in Figure 4.1. These are nominally Columns O to R, the columns with Related Details buttons. The procedure is as follows: In Row 1, in any column in the reserved range, type the name of the Level 1 measure, followed by the name of the particular Level 2 measure, separated by :: (with no spaces). An example would be Measure 2::Measure 2.1. Copying and pasting a name from the *Level 2 Data* sheet may help avoid typographical errors.

Altering Cost-Related Columns

The columns set aside for cost data (nominally T through AB, those with Cost Detail buttons) can be used to display subsets of information in the *Cost Data* sheet. Take a case in which PAT was set up initially to display R&D, acquisition, and O&S costs on the *Summary* sheet for the period 2010–2015. PAT will add a Total Cost column for that period as well. But then suppose the user wants to show two-year costs as well. The additional columns could be added to the summary by simply typing in the correct names in Row 1, probably in columns X, Y, and Z (or at least in columns with Cost Detail buttons). In this case, the user would type in the following names, respectively:[2]

R&D Cost: 2010-2011 ($M)
Acquisition Cost: 2010-2011 ($M)
O&S Cost: 2010-2011 ($M)

To specify a single year, one should use just that year rather than a range (i.e., 2010, rather than 2010-2010).

---

[2] The ($M) is not included in the cost-category name, but is added separately. The names being added cannot be simply copied and pasted from the *Cost Data* sheet.

Figure 4.10 illustrates this example, showing the cost columns of the *Summary* sheet. The columns for the 2010–2015 interval would be generated automatically, but the column for the period 2010–2011 has been added, as mentioned above, by typing in Total Cost (2010-2011) ($M). PAT understands the word "Total" to mean the sum of the costs over the specified cost categories, which in this case are R&D, acquisition, and O&S.

To show all categories of costs for two years rather than the six years, the user could merely edit the column headers, changing 2010-2015 to 2010-2011.

Adding or Deleting Options

Analysts using PAT will frequently enter data for more options than can reasonably be displayed. However, minds change and it is often necessary to add or delete an option in the *Summary* display. This is done simply by inserting a row within the scorecard range and typing in the precise name of the option in Column A.

Cost-Effectiveness

The two rightmost columns in Figure 4.1 are labeled by PAT as Effectiveness and Cost-Effectiveness. The method used to calculate effectiveness is selected from the Cost Effectiveness Scoring Method dropdown menu; the cost metric used in the cost-effectiveness calculation is selected from the Cost-Effectiveness Cost Metric dropdown menu.[3] To make present-value calculations, the user can apply a discount rate to the cost numbers, using the Discount Rate dropdown menu. This should be understood as the real discount rate if the costs in the *Cost Data* sheet are already corrected for inflation, and as the sum of inflation and real inflation rate otherwise.

The cost-effectiveness values are scaled so that the most cost-effective investment option has a value of 1, and all other investment options are compared to it. A no-changes baseline, if present, will always have a cost-effectiveness of 0 (rather than allowing it to be infinity because it involves zero cost).

Figure 4.10
Cost Information in the Summary Sheet

Total Cost: 2010-2015 ($M)	R&D Cost: 2010-2015 ($M)	Acquisition Cost: 2010-2015 ($M)	Operations Cost: 2010-2015 ($M)	Total Cost:2010-2011 ($M)
Cost Detail	Cost Detail	Cost Detail	Cost Detail	Cost Detail
2,561	221	2,000	340	176
2,177	237	1,700	240	190
852	177	285	390	230

[3] This menu sometimes has duplicate versions of the same costs, with slight differences in names.

Comments, Flags, and Warnings

The cell showing the name of an investment option may have a comment, indicated by a red triangle in the upper right corner. Mousing over that cell brings up the comment, which might be a cryptic definition or nuance (Figure 4.11).

If a cell in the scorecard has a similar flag, the flag is a warning. Mousing over it will cause a dropdown to appear with a brief description of what is being warned about (see Figure 4.11).

Finally, mousing over the name of a measure brings up any comment (from the *Level 1 Data* sheet) that may describe the measure; it will also show the measure's weight in effectiveness calculations.

Measure Weights

The weights of the various Level 1 measures used in calculating effectiveness can be shown or hidden as a group by selecting Show/Hide Weights from the Options menu. If the weights are shown (just below the Detail buttons), they can be changed directly, in which case PAT recalculates effectiveness and relative cost-effectiveness immediately, without prompting. PAT also modifies the weights of the measures on the *Level 1 Data* sheet.

Buttons

The *Summary* sheet includes various buttons. Clicking a Detail button will bring up the *Level 2 Drilldown* sheet for the particular measure (column). Clicking a Related Details button for any of the numeric data columns will also bring up the relevant *Level 2 Drilldown* sheet. Clicking the Cost Detail button opens the *Cost Charts* sheet. There is no button directing access to Level 3 information. One accesses *Level 3 Drilldown* as discussed in the subsection on that topic below.

An Illustrative Summary-Level Scorecard

Figure 4.12 shows a condensed version of the scorecard portion of the *Summary* sheet for our simple example. We have chosen to display only the answers plus the measure weights, ignoring the other features of the scorecard. The red rectangle indicates that we will drill down for more information on Measure 2.

Figure 4.11
Warning Flags in a Summary Sheet

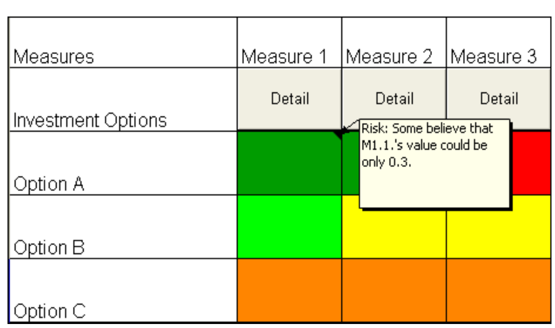


Figure 4.12
Illustrative Summary Scorecard (Level 1)

Level 2 Drilldown Sheet

Clicking on the Detail button for any particular measure in the *Summary* scorecard brings up the *Level 2 Drilldown* sheet, as Figure 4.13 illustrates for Measure 2. This sheet includes a scorecard showing the scores of all contributors to the measure's effectiveness and, on the right side, the calculated consequences (which are the same as the column of scores or colors shown in the *Level 1* scorecard for Measure 2, reading downward: green, yellow, orange). In more typical cases, the scorecard may have from three to seven Level 2 measures and will therefore be more complex.

The default is that Level 2 drilldown is shown for the same settings as specified in the *Summary* (e.g., Thresholds). However, the user can vary the scoring method and weights in this sheet in order to test some variations. He should use the buttons at the top right to make the changes take effect, and he should be cautious about using different scoring systems in the *Summary* sheet and this sheet.

Depending on which options are selected from the two Display menus, only some of the information in the sheet is shown. Users will not always want to see the information above the scorecard. For production purposes, the color-explanation chart at the very bottom is also not very interesting. Figure 4.14 shows a screenshot with many of the upper rows suppressed (using the Display menu) and with the color-explanation chart left out. The rectangle indicates that we will drill down on Measure 2.2. The italic letters in the boxed column indicate that this measure is calculated from Level 3.

At the price of disrupting flow from Figure 4.14 to the *Level 3 Drilldown* sheet, let us first note that *Level 2 Drilldown* displays look somewhat different when other scoring/aggregation methods are used. If the Goals scoring method is selected, cells will be green or red, depending on whether or not the raw value for each Level 2 measure reaches the goal (Figure 4.15). If it does so, the rightmost column gives the weighted percentage of goals achieved over all of the Level 2 measures (for the particular Level 1 measure). The color of the cell in the rightmost column corresponds to the color of the corresponding cell on the *Summary* sheet. If the Thresholds, Weak Thresholds, or Weakest Link scoring/aggregation method is selected, cells in the table are colored red, yellow, or green, depending on whether the raw value (1) does not reach the threshold value, (2) reaches the threshold value but does not reach the goal value, or

Figure 4.13
Level 2 Drilldown Sheet

Scoring Method: Thresholds | Display: All rows | Color Descriptions | Recalculate Drilldown | Update Level 2 Data Sheet
☑ Use 5-color display

Level 1 Measure	Measure 2				
Level 2 Measure	Measure 2.1	Measure 2.2	Warning		
Weight of Level 2 Measure in Scoring Functions (0 to 1)	1	1	0		
High or Low Values Desired?	High	High			
Threshold Value	0	0	0		
Goal Value	1	1	0		
Level 2 Measure Score for Threshold Value (0 to 1)	0	0	0		
Level 2 Measure Score for Goal Value (0 to 1)	1	1	0		
Investment Option				Measure 2 Score	
Option A	G	G		G	
Option B	LG	Y		Y	
Option C	Y	R		O	
Color Code	G	LG	Y	O	R
Level 1 and Level 2 Measure Score	0.8 to 1.0	0.6 to 0.8	0.4 to 0.6	0.2 to 0.4	0.0 to 0.2 or Failure (F)

(3) reaches the goal value, respectively. The color of the cell corresponds to the measure score, with the maximum score being 1 (corresponding to green) and the minimum score being zero (corresponding to red).

For the Rankings scoring method (Figure 4.16), each Level 2 measure is ranked individually, with colors on a light blue to dark blue scale showing how the investment options rank relative to one another. The rightmost column shows a weighted average ranking. The score and color of the cell will be carried up to the *Summary* sheet for that investment option and measure.

Figure 4.14
Compressed Version of Level 2 Drilldown for Measure 2

Level 2 Measure	Measure 2.1	Measure 2.2	Warning	
Investment Option				Measure 2 Score
Option A	G	G		G
Option B	LG	Y		Y
Option C	Y	R		O

Figure 4.15
Level 2 Drilldown with Goals Method

Level 2 Measure	Measure 2.1	Measure 2.2	Warning		
Investment Option				% of Goals Reached (Weighted)	
Option A	G	R		Y	
Option B	R	R		R	
Option C	R	R		R	

Figure 4.16
Level 2 Drilldown with Rankings Method

Investment Option				Average Rank		
Option A	1 (1.00)	1 (0.80)		1.00		
Option B	2 (0.60)	2 (0.50)		2.00		
Option C	3 (0.50)	3 (0.00)		3.00		
Color Code						
Meaning	Avg Rank in Top Quintile	Avg Rank in 2nd Quintile	Avg Rank in 3rd Quintile	Avg Rank in 4th Quintile	Avg Rank in Bottom Quintile	

The raw values and the scoring-function parameters may be edited in the *Drilldown* sheets, even though they are nominally output sheets. Once the data and parameters have been changed, the user should click on the Update Level 2 Data button, which will update the data sheets and will also recreate the *Summary* and *Drilldown* sheets with the new information.

Level 3 Drilldown Sheet

Returning now to the stream of examples using the Thresholds scoring method, and picking up with the drilldown shown in Figure 4.13, the *Level 3 Drilldown* sheet is shown in Figure 4.17. To access it requires a small change of procedure. The user must first click on the Level 3 Drilldown tab or go to that sheet using the Go To Sheet menu at the top of the Excel window. When the next screen comes up, the user must take the additional step of selecting the desired Level 3 measure from the Level 3 Drilldown Options menu at the top left (not shown). The result is shown in Figure 4.17 for our continuing simple example. In this chart, however, we have chosen (using the display menus) to show the numerical raw-value figures that determine the colors. They might be suppressed in a presentation, but the analyst sometimes finds them useful.

Note that the final column shows scores of green, yellow, and red (reading downward), which agrees with the column for Measure 2.2 in Figure 4.13.

Figure 4.17
Level 3 Drilldown for Measure 2.2

Level 1 Measure	Measure 2				
Level 2 Measure	Measure 2.2				
Scoring Method	Thresholds				
Level 3 Measure	Measure 2.2.1	Measure 2.2.2			
Weight of Level 3 Measure in Scoring Functions (0 to 1)	1	1			
Investment Option			Measure 2.2 Score		L2 Score (0, 0; 1, 1)*
Option A	LG 8.00	G 10.00	0.8 G 0.80		G 0.80
Option B	O 6.00	G 9.00	0.5 Y 0.50		Y 0.50
Option C	R 4.00	R 2.00	R		R 0.00

The reader may wonder why such drilldown charts have two apparently identical columns on the right, entitled Measure 2.2 Score and Level 2 Score. To explain, suppose that we change the assumptions of our simple problem slightly, by specifying a threshold value for Level 2 Measure 2.2. In that case, results would change, and the Level 3 explanation would look like Figure 4.18.

If we scan the colors at the left of the row for Option A (ignoring the numbers for a moment), it may seem that they don't average correctly. For example, Measures 2.2.1 and 2.2.2 are light green and green, averaging to green in the Measure 2.2 Score column. That is perhaps reasonable. But why, then, is the Level 2 score yellow? We will walk through the calculations, because they are somewhat subtle. Note first from the rows above the scorecard that the Measures 2.2.1 and 2.2.2 have Level 3 thresholds of 5 and 5. Thus, averaging the raw values in this case produces (1/2) [(8 – 5)/5 + (10 – 5)/5] or 0.8, as shown in the Measure 2.2 Score column. That is, the scoring "starts" at a raw value of 5. In this case, however, Level 2 also has a threshold. The small-print parenthetical expression below the Level 2 score tells us about this without our having to look in the *Level 2 Drilldown* sheet. The syntax of (0.51, 0, 1, 1) means (see the note at the bottom of the display) that the threshold is 0.51, the score at the

Figure 4.18
Level 3 Drilldown If Measure 2.2 Has a Threshold Value

Level 1 Measure	Measure 2				
Level 2 Measure	Measure 2.2				
Scoring Method	Thresholds				
Level 3 Measure	Measure 2.2.1	Measure 2.2.2			
Weight of Level 3 Measure in Scoring Functions (0 to 1)	1	1			
High or Low Values Desired?	High	High			
Threshold Value	5	5			
Goal Value	10	10			
Level 3 Measure Score for Threshold Value (0 to 1)	0	0			
Level 3 Measure Score for Goal Value (0 to 1)	1	1			
Investment Option			Measure 2.2 Score		L2 Score (0.51, 0; 1, 1)*
Option A	8.00	10.00	0.80		0.59
Option B	6.00	9.00	0.50		0
Option C	4.00	2.00			0
Color Code					
Level 2 and Level 3 Measure Score	0.8 to 1.0	0.6 to 0.8	0.4 to 0.6	0.2 to 0.4	0.0 to 0.2 or Failure (F)

* Numbers indicate Measure's Level 2 settings for threshold value (0.51), threshold score (0); goal value (1), and goal score (1), respectively.

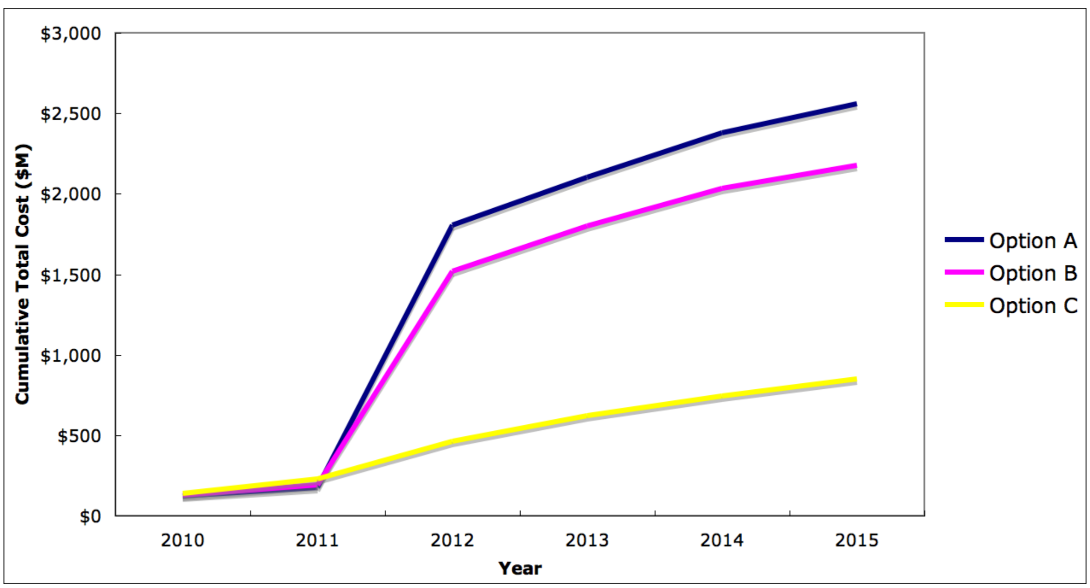
threshold is 0, the goal is 1, and the score at the goal is 1. The value of 0.8 to be evaluated (the Measure 2.2 score) is 59 percent of the way between 0.51 and 1. Thus, the Level 2 score is 0.59, as shown, which is just within the range associated with yellow.

PAT's flexibility in allowing the user to attach goals and thresholds is powerful, but using goals and thresholds requires caution and attention to detail—especially if they are used at both Levels 2 and 3.[4] One price is that a "visual explanation" may not be enough in drilldowns; it may be necessary to look at the details, as with Figure 4.13.

Cost Data Sheet

Costs are an input to PAT, as discussed in Chapter Three (see Figure 3.4), but PAT also generates output charts. If, for example, the user specifies cost streams for categories R&D, acquisition, and O&S by option, by year, the *Cost Data* sheet will show plots of yearly or cumulative cost, by option and category, or total costs across categories. Figure 4.19 illustrates the latter. It expresses costs in current dollars (also called current-year or then-year dollars), but the user will often wish to use constant dollars (also called real dollars) or present-value calculations, as discussed in Chapter Three.

Figure 4.19
Illustrative Total Costs Versus Time Chart



NOTE: The example uses current (i.e., then-year) dollars, but the user can specify use of constant dollars instead.

[4] An example of this complexity might be a set of Level 3 measures related to risk.

Scatter Plot Sheet for Cost-Effectiveness Landscapes

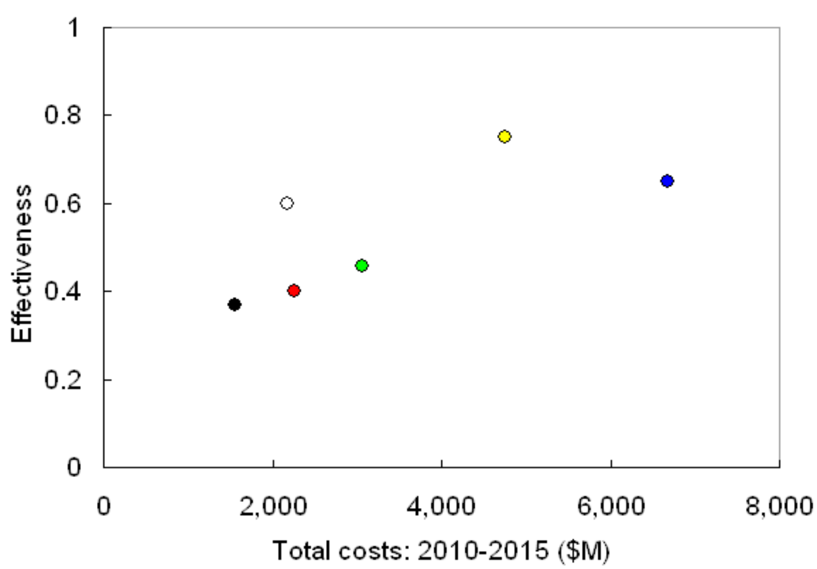
PAT's built-in *Scatter Plot* sheet allows the user to construct cost-effectiveness landscapes, i.e., plots of effectiveness (or another measure of performance) versus cost. The user can choose any one cost metric and any two evaluation metrics from menus on the *Scatter Plot* sheet. The cost metrics on the menu are generated from the cost categories and any specialized cost metrics used on the *Summary* sheet. The evaluation metrics may be any of the Level 2 measures or an effectiveness score calculated by any of the built-in methods (e.g., Threshold or Weakest Link). The chart presents points representing the options located by cost (x-axis) and effectiveness metric (vertical y-axis or axes). Mousing over a point reveals which option the point refers to.

These cost-effectiveness landscapes are quite useful when evaluating choices with economic constraints. They can illustrate both the classic phenomenon of diminishing returns and, e.g., the "chunkiness" phenomenon, in which as cost increases, larger increases are necessary before there are significant increases in effectiveness.

Figure 4.20 shows a scatter plot with six options. In this case, the behavior is classic: Effectiveness rises with cost, but at a diminishing rate. And at any given cost level, there are better and poorer performers.

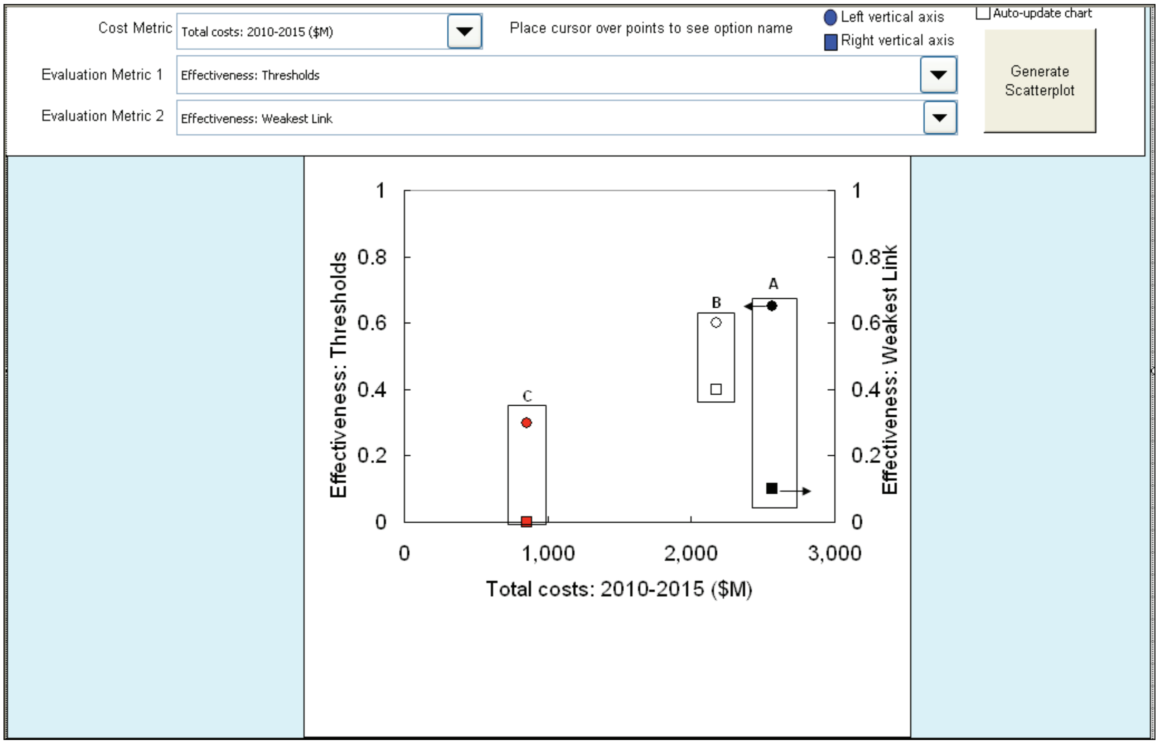
Figure 4.21 shows the *Scatter Plot* sheet for the simple example used in this report, which has only three options. It also shows the controls for the scatter plot. For this display, we chose to evaluate the options for both the Thresholds and Weakest Link methods. In this case, the relative goodness of the options is unchanged, but that will not always be so.

Figure 4.20
Illustrative Scatter Plot



NOTE: The points are individual options. Their names are revealed by mousing over them or by changing the relevant chart option. Costs in this figure are given in current (then-year) dollars.

Figure 4.21
Scatter Plot for the Simple Problem, Using Two Scoring Methods



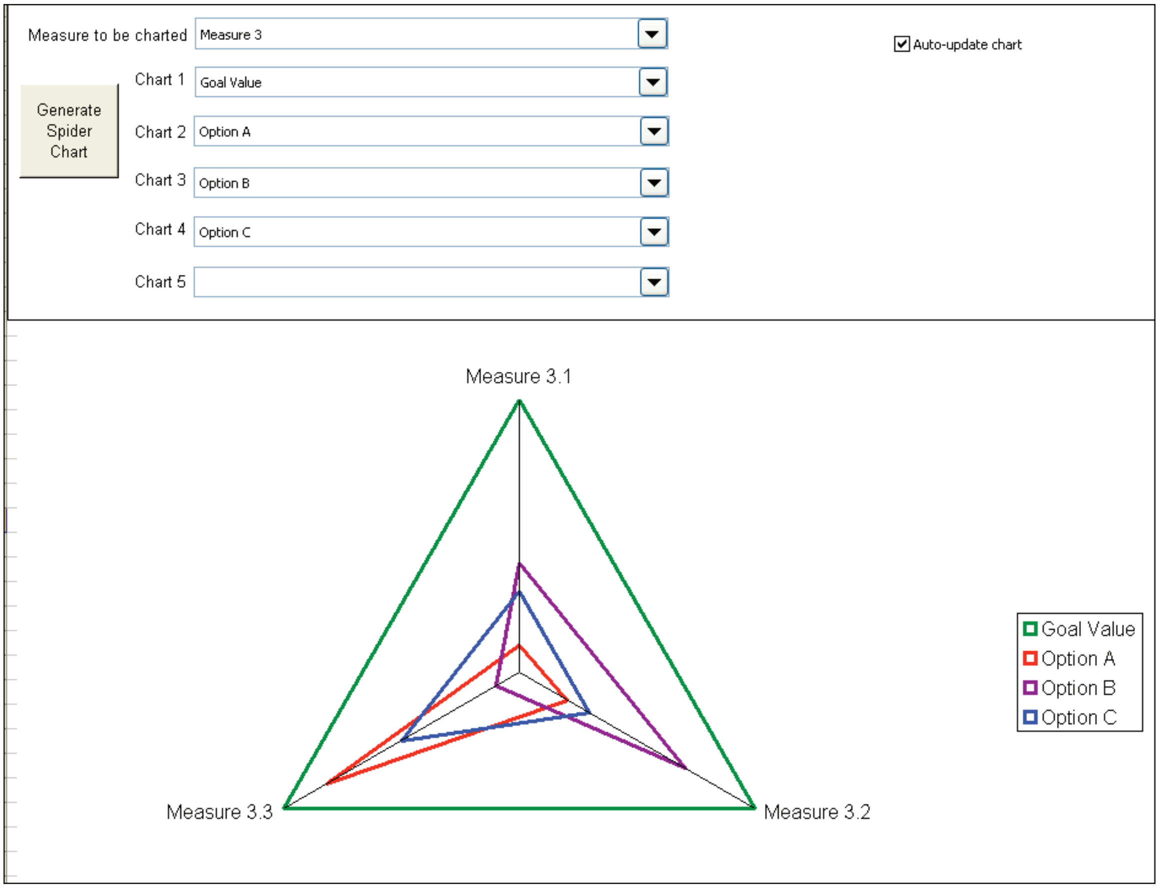
Changing the evaluation metric or any of the investment options will automatically regenerate the *Scatter Plot*, as will clicking on the Generate Scatterplot button, which should be used when changes are made in the data for the various options given in the Levels 2 and 3 databases. The scatter plot will not update for such changes automatically, in part because it is convenient to have the chart remain constant while one looks at other sheets. Another reason for constancy is that when Excel regenerates charts, it restores default formatting, which may undo a good deal of work. If the user does want automatic regeneration, however, he needs only to click the appropriate box.

Spider Charts Sheet

The *Spider Charts*[5] sheet (Figure 4.22) allows the user to select a measure and up to four investment options. The goal and threshold values for the Level 2 measures may be inputted instead of two of the investment options. The Level 2 measures of the selected Level 3 measure are shown as arms of the spider chart. The values in the spider chart are scaled relative to the investment option (or goal or threshold value) selected as Chart 1. Also, PAT inverts the scales, if necessary, so that in all cases, more is better; i.e., the farther out an option extends, the better. There are no values on the axes because the purpose of the chart is merely to communicate visually a sense of relative effectiveness by different measures. Changing the measure to be charted or any of the investment options will automatically regenerate the spider chart, as

[5] Spider charts are also called "radar charts."

Figure 4.22
Illustrative Spider Plot

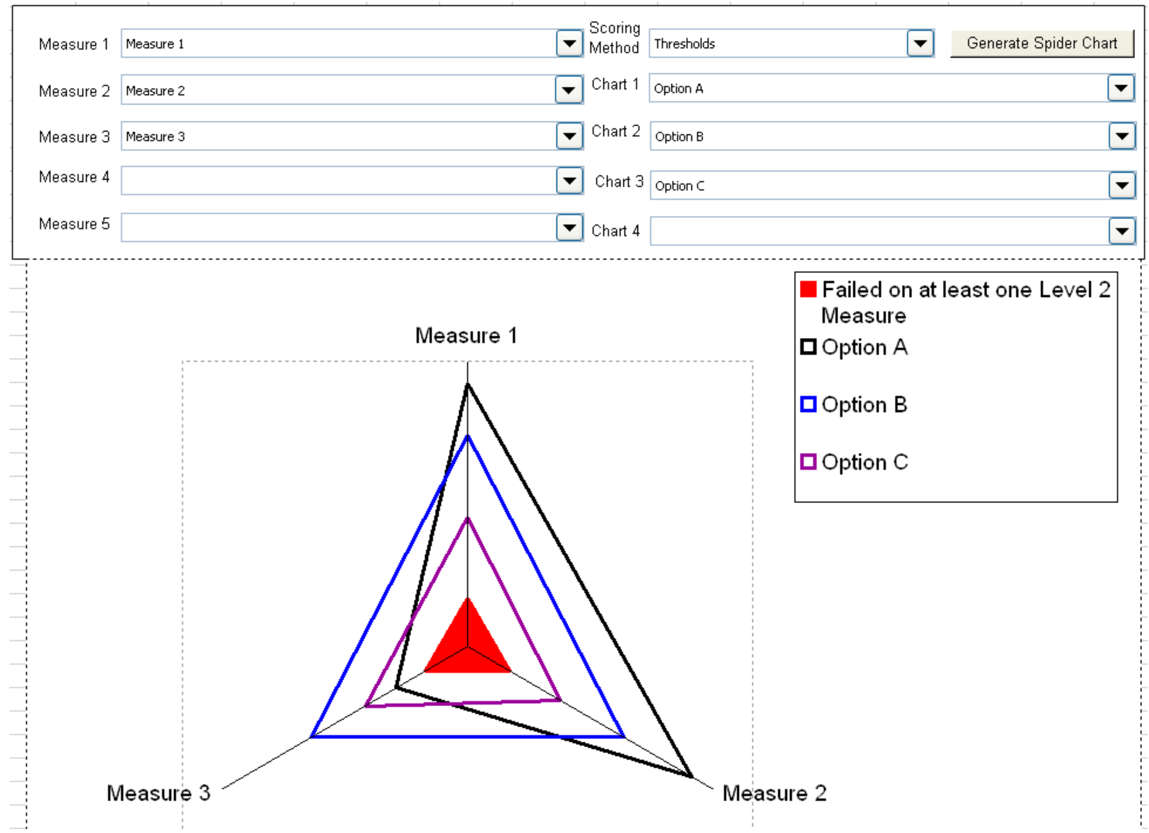


will clicking on the Generate Spider Chart button, which should be used when the raw values or parameters on the data sheets are changed.

Multimeasure Spider Charts Sheet

Multimeasure spider charts (Figure 4.23) provide a visual depiction across different Level 1 measures. For each investment option displayed on the spider chart, the values along each arm correspond to the average rank for the Rankings scoring method or the measure score for the other scoring methods. For the Thresholds scoring method, if any investment option for a sub-measure fails, the value for the corresponding measure falls inside a red polygon representing failed measures. The user can select the scoring method, using the Scoring Method dropdown menu, and up to four investment options. Changing either will regenerate the spider chart, as will clicking on the Generate Spider Chart button, which should be used when the raw values or parameters on the data sheet are changed.

Figure 4.23
Multimeasure Spider Plot



Selected Details Sheet

Figure 4.24 generates a *Selected Details* display similar to the *Drilldown* sheets, except that the Level 2 measures in the columns are specifically chosen for the purposes of the particular analysis for which PAT is being used and may come from different measures. That is, whereas the *Drilldown* sheets relate to a particular measure, the *Selected Details* sheet allows the user to tailor a display with details selected from several measures. As with the data sheets, all scoring methods and the associated color schemes may be displayed on the *Selected Details* sheet by using the Scoring Method dropdown menu. The dropdown menus allow selection of the available measures, using the format Measure::Submeasure.

Rankings Table Sheet

Figure 4.25 shows the *Rankings Table* sheet, in which the investment options are ranked by effectiveness (or cost-effectiveness) for each perspective defined on the *Perspectives* sheet. The scoring method and cost metrics used can be selected from menus. In each cell, the rank is shown in large bold text, and the relative (cost-)effectiveness appears in parentheses under the

Figure 4.24
Selected Details Sheet

Scoring Method: Thresholds	List of all Category/Subca	List of all Category/Subca	Measure 3::Measure 3.1
Level 1 Measure	Measure 2	Measure 2	Measure 3
Level 2 Measure	Measure 2.1	Measure 2.2	Measure 3.1
Weight of Level 2 Measure in Scoring Functions (0 to 1)	1	1	1
High or Low Values Desired?	High	High	High
Threshold Value	0	0	0
Goal Value	10	1	10
Level 2 Measure Score for Threshold Value (0 to 1)	0	0	0
Level 2 Measure Score for Goal Value (0 to 1)	1	1	1
Investment Option			
Option A	10	0.8	1
Option B	6	0.5	4
Option C	5	0	3

Figure 4.25
Rankings Table Sheet for Effectiveness or Relative Cost-Effectiveness

Scoring Method: Thresholds ☑ Rank on cost-effectiveness (instead of effectiveness) Cost Effectiveness Cost Metric: Total costs: 2010-2015 ($M) ☑ Auto-update chart **RANKING** (Relative (Cost-)Effectiveness)	Default	Baseline (1,1,1)	Measure 1 Emphasis (2,1,.5)	Weakest Link (2,1,.5)
Option A	**3 (0.33)**	**3 (0.74)**	**2 (0.88)**	**2 (0.88)**
Option B	**2 (0.39)**	**2 (0.89)**	**3 (0.87)**	**3 (0.87)**
Option C	**1 (1.00)**	**1 (1.00)**	**1 (1.00)**	**1 (1.00)**

ranking. The investment option with the highest absolute (cost-)effectiveness for each perspective is given a relative cost-effectiveness of 1, with all other cost-effectiveness values measured against it. The same scaling is used with effectiveness (not shown).

CHAPTER FIVE

Details of the Methodology

This chapter repeats some of the earlier material from Chapter Two in order to be relatively self-contained, but its purpose is to generalize, lay out the mathematics, comment on some of the subtleties of the methodology, and work through an example.

Basic Concepts and Definitions

Figure 5.1 indicates how PAT operates analytically (except with the *Rankings* method discussed below, under Alternative Methods). For each investment option, PAT takes a series of inputs (grayed items) and characterizes how well the option performs by different criteria, including cost-effectiveness. The illustrative figure assumes n measures, of which only the first and the nth are shown. A given measure might be calculated from a combination of Level 2 and Level 3 data (as shown for Measure 1) or might be specified directly (as shown for Measure n).[1]

The following paragraphs explain the PAT concepts and terminology.

Attributes of Investment Options

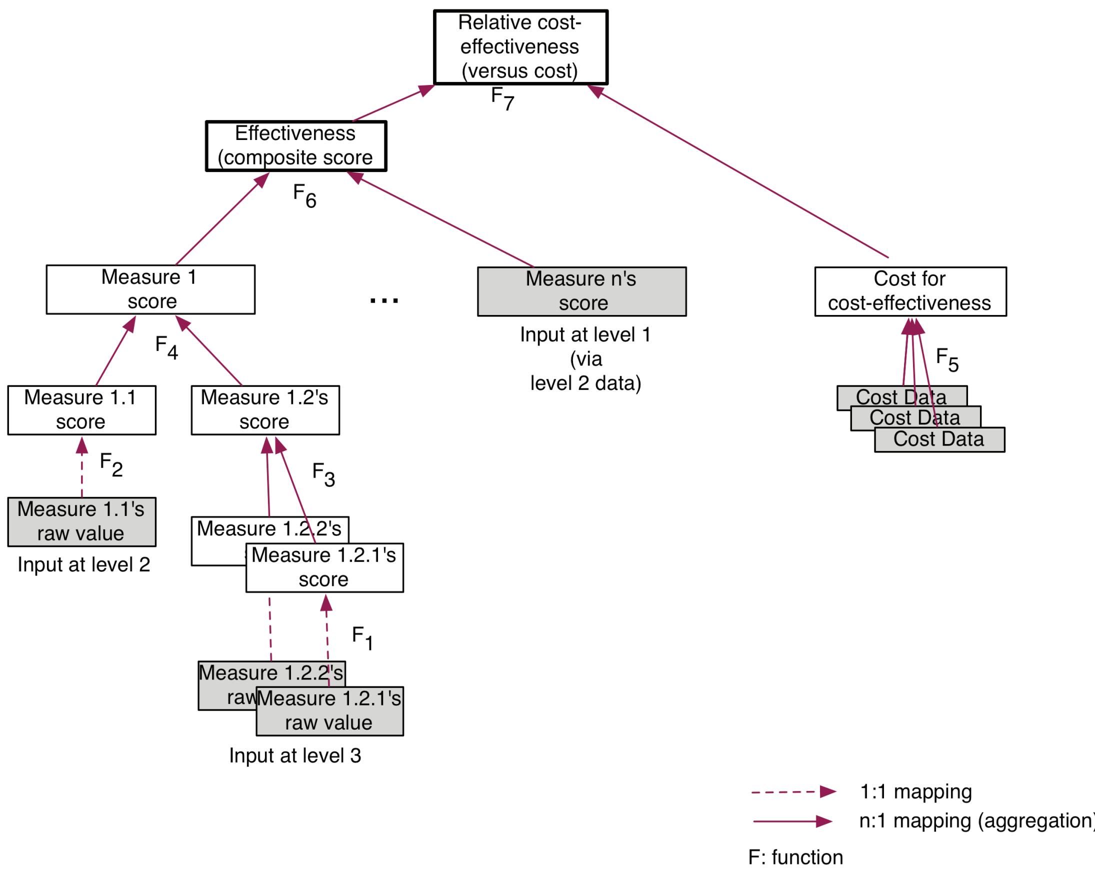
The investment options are alternative programs of investment over time. Each investment option has a number of attributes, described below.

Input Costs. Each PAT investment option must have an associated investment stream, specified by projected cost for each year, cost category (e.g., R&D, acquisition, and O&S), and expenditure item (e.g., ships, aircraft) of interest for the analysis. Such data can be rather complex but can be simplified to, e.g., by using a single category (Total), a single type of item (General), or a short time period.

The required cost streams are inputs expressed in current (i.e., then-year) dollars or dollars corrected for inflation. The initial data available to the PAT analyst will often be a combination of detailed cost streams and fragments of other, more aggregated information such as the projected 20-year or Future-Years Defense Plan (FYDP) cost of a weapon system or type of force unit. The PAT user, then, must draw on such heterogeneous information to estimate the cost streams required for PAT as best he can. He may choose to make simplifying approximations, such as spreading aggregate costs equally over the entire time period.

[1] As a matter of implementation, to specify a Level 1 measure directly in PAT, one defines the measure as a function of only one Level 2 measure. It is that Level 2 measure that is directly inputted.

Figure 5.1
Schematic of PAT's Calculations



NOTE: Grayed items are inputs.

Output Cost. After constructing PAT-consistent cost data (typically in inflation-adjusted dollars) for his options, the analyst may use PAT (or custom worksheets within PAT) to generate cost information in many different forms. Some of this activity will require merely manipulating the core data in different ways, but some will involve calculation. For example, the analyst may wish to generate present-value costs for various options.[2] If so, he must specify a real discount rate (or a set of rates to use for bounding the problem). The formula used for the present value of a set of payments to be received over *n* years is

$$PV = \sum_{i=1}^{n} \frac{E_i}{(1+DR)^i}$$

[2] A promise to pay someone $1 million in ten years is less painful than paying $1 million now, because one could invest the $1 million for ten years, pay the debt at that point, and keep the returns. The economic calculations are well understood, as discussed in many sources, including *Wikipedia* (Hitch and McKean, 1965), but the real discount rate is controversial and dependent on the particular problem considered. It is arguably good practice to calculate for *real* discount rates of both 0.03 and 0.07 to bound the calculations. For discussion of how the Government Accountability Office (GAO) came to suggest this, see Graham, 2007. Such issues were addressed in a recent RAND study of the resource implications of alternative U.S. global military strategies (Davis et al., 2008).

where

DR = real discount rate

E_i = payment promised at end of ith year, in real (inflation-protected) dollars.

The sign is positive or negative, depending on whether one is receiving or paying and on the syntax of discussion. If the yearly expenditures are expressed in current (i.e., then-year) dollars (without correction for inflation), the formula is

$$PV = \sum_{i=1}^{n} \frac{E_i}{(1+I)^i (1+D)^i} \approx \sum_{i=1}^{n} \frac{E_i}{(1+DR)^i}$$

where

D = nominal discount rate

E_i = payment promised at end of ith year, in real (inflation-protected) dollars.

DR = $D + I$

The approximation is good except for very high rates of inflation. From a simple Taylor's expansion, the first-order correction would be a factor of I, i.e., 0.97 for 3-percent inflation.

Measures and Submeasures (Level 1, 2, and 3 Measures), Raw Values, and Scores

The options are characterized at the *Summary* level by criteria called "measures" or "Level 1 measures," each of which has one or more submeasures at Levels 2 or 3, or both. We refer to the measures in shorthand as Level 1, Level 2, and Level 3 measures. If we refer to submeasures, we include both Level 2 and Level 3 measures or just Level 3 measures, depending on context. A given input to PAT is usually made at either Level 2 or Level 3. If a particular input is made at Level 3, then Level 2 information is calculated. As is the case throughout mathematics and computer science, the same label (e.g., "a missile's single-shot kill probability") is used to refer to the abstract concept that a measure or submeasure represents and also the value ascribed to that measure.

The measures and submeasures may relate to various types of capabilities or risk. They are akin to metrics, but it is important to distinguish between the intended measure's concept and the metric that is used to represent it. For example, one may wish to assess a force structure's capability for "short-warning" cases. That is an abstraction, whereas the evaluation for a particular planning scenario intended to represent short-warning cases is a metric. Such an evaluation depends not only on the scenario, but also on measures of outcome, the models employed, and the detailed inputs to those models.

Raw Values of Submeasures. We refer to inputs in terms of "raw values."[3] For a weapon system, such data might come from system specifications and an assumption that the specifications will be met, from test data, from models, or from expert judgment. For high-level strategic assessments of force structure, the inputs might be subjective but based on a strong analytic background of modeling, war gaming, and operations. The raw values may be expressed in different units and on different scales. They may be objective or subjective. A larger raw value

[3] If Level 2 measures are specified directly, they may be specified either as raw values on an arbitrary scale or as scores between 0 and 1, with higher being better.

may be good or bad, depending on how the quantity in question is defined. Technical risk as measured by likelihood of failure during a mission is better if it is smaller. Technical risk as measured by mean time before failure is better if it is larger.

By themselves, such raw values do not convey a sense of sufficiency. For that, we need to introduce goals and thresholds.

Goals and Thresholds. All of the methods used in PAT except the Rankings method involve goals, thresholds, or both. Inputs to PAT include, for each submeasure, a raw value corresponding to the goal and a raw value corresponding to a threshold (a minimum level for perceived utility).

Submeasure Scores. PAT calculates the score of a submeasure from its raw value, goal, and threshold. Except with the Rankings method (discussed below), the score is between 0 and 1, with 1 always being good.

Measure Scores. The score of a measure is calculated from the scores of its submeasures. That is, a measure's score is an aggregation of its submeasure scores.[4] Except with the Rankings method, measure-level scores (or, simply, scores) are defined as being between 0 and 1.

Overall-Effectiveness Scores. Once PAT has calculated scores for the measures characterizing the investment options, it can also generate the options' scores for effectiveness, which is shorthand for composite or overall effectiveness.

Relative Cost-Effectiveness

An option's cost-effectiveness is the ratio of its effectiveness and cost, but different costs can be used for the denominator. A PAT user can select any of the inputted cost categories (e.g., R&D, acquisition, or O&S) or their total for the inputted time span (e.g., 2010–2029). PAT then calculates an intermediate cost-effectiveness for each option (not shown in Figure 5.1), uses the largest value as the base, and compares all options' cost-effectiveness to that. The result, then, is the relative cost-effectiveness for each option.

Methods and Functions

The progression summarized in Figure 5.1 requires numerous functions (F_1,F_2, . . . ,F_7), as indicated in Figure 5.1. These accomplish the following transformations:

- From submeasure raw values to next-level scores (from Level 3 to Level 2, and from Level 2 to Level 1).
- From submeasure scores to measure-level scores (potentially at both Levels 2 and 3).
- From costs of various types to a single cost used in cost-effectiveness calculations.
- From Level 1 scores to effectiveness scores.
- From effectiveness scores and cost to cost-effectiveness.

The different methods in PAT to which we have alluded use different functions, as discussed in the next section.

[4] A more rigorous term is "abstraction." A measure abstracts from or captures the relevant essence of the submeasures. It may be a simple average, or it may be a more context-sensitive projection. Historically, "aggregation" meant the result of collecting, e.g., one might aggregate the strengths of nine battalions to estimate the strength of a division. It is coming to have a more general meaning akin to "abstraction" (Zeigler, Praenhofer, and Kim, 2000).

Summary of Definitions

Table 5.1 summarizes the terms used in PAT and their meanings and includes an example of each.

Alternative Methods

The Need for Alternative Methods

Each of the steps in Figure 5.1 requires specifying the appropriate mathematical function.[5] In a given application of PAT, this is accomplished when the analyst chooses a scoring method.

Table 5.1
A Glossary of PAT Terminology

Term	Meaning in PAT	Examples
Abstraction	A generalization derived from more detailed or concrete cases, perhaps for a particular context of use; measures are abstractions of submeasures	• Engagement effectiveness as derived from radar, missile, and kill-vehicle effectiveness • Effectiveness of an Army brigade for different classes of combat, relative to a "standard" brigade
Aggregation	Abstraction	• Ten-year cost • Overall risk derived from technical, strategic, and political risks
Cost-effectiveness	The ratio of an effectiveness score to a measure of cost	—
Effectiveness	A composite score formed by abstracting from the scores of one or more measures	• Combat effectiveness of a force structure, based on model outcomes for diverse scenarios
Measure	A way of evaluating something; a dimension of an assessment (similar to a metric)	• The size of attack that saturates a defensive system • The likelihood of campaign success in a specified planning scenario
Method	A procedure used to map raw scores into scores or to calculate higher-level scores from lower-level scores	• Linear weighted sums • Threshold-modified linear weighted sums • Weakest link
Raw value of a submeasure	An unscaled value of a submeasure	• The size of attack that saturates a defensive system • The number of simultaneous conflicts with which U.S. forces could deal
Relative cost-effectiveness	The ratio of an option's cost-effectiveness to that of the option with the highest cost-effectiveness	—
Score	A value between 0 and 1 derived from raw values and goals to convey a sense of goodness	• The value of a brigade in comparison with that of a "standard" brigade
Submeasure	One of the factors determining a parent measure	• The size of attack that saturates a defensive system in a particular case (e.g., with attacker countermeasures)

[5] All of PAT's relevant functions are monotonic non-decreasing (they are not convex, however, as can be seen in Figure 5.2). Thus, improving performance of an investment option in some submeasure cannot decrease the effectiveness score. The aggregations to an overall effectiveness score have the same property. More to the point, our scoring methods do not lead to counterintuitive conclusions (except in obscure cases that have no significance).

Most work in mathematical decision analysis uses the method of linear weighted sums contributing to a single measure of "utility." That method is taught in many schoolbooks and embedded without comment in much decision-support software.[6] It is often quite useful, but in strategic planning, capabilities-based planning, and in much of systems analysis and policy analysis more generally, it is flawed, for several reasons:

- Decisionmakers need to know about some of the "apples and oranges" separately; aggregation into a single utility suppresses too much information and depends too heavily on underlying assumptions and preferences that are properly in the decisionmaker's province rather than the analyst's.[7]
- As decisionmakers sometimes observe, "Who knows what it means for an option to score 0.74 rather than 0.77?" Such aggregate indexes often have no intuitive significance beyond "more is better."
- Similarly, decisionmakers need to know how a given option addresses each of their separate high-level objectives.[8]
- Aggregation rules sometimes need to be nonlinear because of "system effects," as described in the following examples.

First Example: Ballistic Missile Defense. In reviewing his program, the Director of MDA needs to understand separately the current and projected capabilities for different missions (homeland defense, defense of allies, and defense of U.S. forces deployed abroad). Further, he needs to understand how well the defense system would do against both small and large attacks and against attacks with and without various countermeasures. There is no single way to roll all such information meaningfully into a single measure. Further, at a more technical level, the effectiveness of a defense system for a particular mission and a particular attack depends in a nonlinear way on the effectiveness of the system's components (e.g., sensors, interceptors, and kill vehicles). If any one of those fails, the system fails, regardless of how well the other components perform. Representing such system issues implies using nonlinearities in the mathematics (Davis, 2002a).

Second Example: Joint and Combined Forces. The Secretary of Defense might wish that overall force-structure effectiveness could be reduced to a single number, but he needs to see separately measures of the capability of air, ground, and sea forces for a variety of geographic regions and operational circumstances. Further, he knows that overall warfighting effectiveness in any particular scenario depends on the balance among the types of forces: More aircraft cannot compensate for lack of infantry in some irregular-warfare scenarios, and more mechanized forces cannot compensate for ceding air superiority to the adversary or for losing the ability to support and sustain operations through sea- and air-logistical chains. Again, representing such system issues implies using nonlinearities in the mathematics.

To reflect common system-related issues, something other than simple linear sums is needed. There are a number of possibilities, ranging from using a multiplicative relationship instead of an additive one to methods that involve enforcing threshold requirements for each of the critical components. In PAT terminology, this corresponds to enforcing threshold requirements for each submeasure that characterizes an investment option.

---

[6] The classic introductory book on decision analysis (Raiffa, 1968) is quite readable. A later text treats multiobjective decision analysis (Keeney and Raiffa, 1976). Although it emphasizes combining sums into a single utility, the book discusses alternatives to simple linear weighted sums.

[7] This consideration has led to policy analysis' emphasis on scorecards. An early RAND application—to a Netherlands water-management problem (Goeller et al., 1983)—was particularly influential in causing scorecards to be adopted.

[8] Value-focused thinking is a form of multiobjective decision analysis that organizes around an organization's objectives (Keeney, 1992). It has been used in a number of military applications (see, e.g., Parnell, 2006).

PAT has five built-in methods for aggregation of scores. This greatly increases flexibility, but it also increases complexity and can undercut the goal of having relatively simple, logical, and intuitive results. Thus, the analyst should decide which method or methods to use and then present only those. The five methods (and their short names) are as follows: (1) goal-based (Goals); (2) goal-based with weak thresholds (Weak Thresholds), (3) goal-based with thresholds (Thresholds), (4) goal-based with weakest link (Weakest Link), and (5) rankings-based (Rankings).

These are described one by one below and are then summarized in Table 5.5 on p. 65. For each method, the description specifies how scores are generated from the raw values of submeasures and how higher-level scores and effectiveness are calculated by aggregation.

We use a common notation, as defined in Table 5.2. The notation and subsequent discussion apply only to problems limited to Level 1 and Level 2 measures but can easily be generalized to the case that has Level 3 measures as well.

Goals Method

The Goals method is the simplest to describe. Every measure is composed of a collection of submeasures, each of which has a goal value that each investment option is trying to achieve.

Submeasure Scores with Goals Method. A submeasure's score is 0 or $G_{j,k}$, depending on whether or not the raw value has reached the goal. That is, for any investment option *i* and any measure *j*, if the scale is increasing so that goals correspond to high values, then the *k*th submeasure's score is given by

$$S_{i,j,k} = 0 \text{ if } V_{i,j,k} < V^G_{j,k}$$
$$S_{i,j,k} = G_{j,k} \, \mathit{if} \, V_{i,j,k} \geq V^G_{j,k}$$

If goodness increases with decreasing raw values, the equations change accordingly.

Aggregation to Find Measure Scores with Goals Method. The function used to calculate the score of a measure is just a weighted sum of the submeasure scores:

$$M_{i,j} = \frac{\sum_{k=1}^{n_j} W_{j,k} S_{i.j.k}}{\sum_{k=1}^{n_j} W_{j,k} G_{j,k}}$$

If all submeasures are equally weighted, the measure score is the fraction of the measure's submeasures that reached their goals. The resulting measure scores are between 0 and 1 because of the normalization accomplished by the denominator. In practice, with PAT, the values of $G_{j,k}$ will usually be set to 1, with the $W_{j,k}$ values establishing the relative weights of the submeasures, but for the sake of completeness, we include $G_{j,k}$ in our equations.

Table 5.2
Notation for Defining Scoring Methods

Symbol	Meaning	Source
i, j, k	Indexes for investment option, measure, and submeasure, respectively	n/a
m	Number of measures	n/a
n_j	Number of submeasures of measure *j*	n/a
$\{V_{i,j,1}, V_{i,j,2}, \ldots V_{i,j,n}\}$	Raw values of the submeasures for investment option *i* and measure *j*	Level 2 or Level 3 Data
$\{S_{i,j,1}, S_{i,j,2}, \ldots S_{i,j,n}\}$	Scores of the n_j submeasures (submeasure scores) for investment option *i* and measure *j*	Calculated
$\{M_{i,1}, M_{i,2}, \ldots M_{i,m}\}$	Scores of the *m* measures (measure scores) for investment option *i*	Calculated
E_i	Overall effectiveness of investment option *i*	Calculated
$\{V^T_{j,1}, V^T_{j,2}, \ldots V^T_{j,n}\}$	Threshold raw values for each submeasure of measure *j*	Level 2 or Level 3 Data
$\{V^G_{j,1}, V^G_{j,2}, \ldots V^G_{j,n}\}$	Corresponding goal raw values for each submeasure of measure *j*	Level 2 or Level 3 Data
$\{T^G_{j,1}, T^G_{j,2}, \ldots T^G_{j,n}\}$	Submeasure scores when submeasure raw values have reached thresholds under measure *j*	Level 2 or Level 3 Data
$\{G_{j,1}, G_{j,2}, \ldots G_{j,n}\}$	Scores of submeasures that have reached their goals under measure *j*	Level 2 or Level 3 Data
$\{W^G_{j,1}, W^G_{j,2}, \ldots W^G_{j,n}\}$	Weights of the submeasures in computing measure scores	Level 2 or Level 3 Data
$\{C_1, C_2, \ldots C_m\}$	Weights of the measures in computing effectiveness	Level 1 Data

Aggregation to Find Overall Effectiveness with Goals Method. The function used to set the overall effectiveness under investment option *i* is also a weighted sum over measures:

$$E_i = \frac{\sum_{j=1}^{m} C_j M_{i,j}}{\sum_{j=1}^{m} C_j}$$

The measure and effectiveness scores all have values between 0 and 1. The weights need not be between 0 and 1, since PAT performs normalizations, but it is arguably good practice to enter weights in that range that add up to 1 so that the significance of a given weight's value will be more readily understood without the user having to look at the other weights and do a mental calculation.

Weak Thresholds Method

Submeasure Scores with Weak Thresholds Method. With the Weak Thresholds method, each submeasure has a threshold and a goal. If the threshold is not reached, the submeasure score is 0. If the submeasure reaches or exceeds its goal, the submeasure score is its score for the goal value. In between, the score is determined by a linear relationship. That is, in cases where goodness increases with raw value:

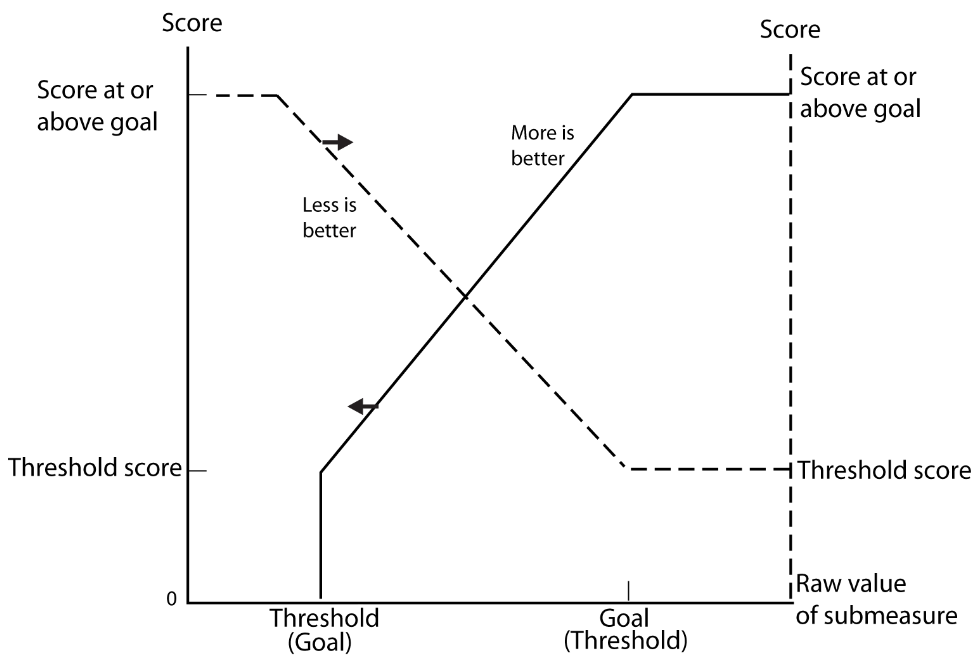
$$S_{i,j,k} = 0 \qquad \text{if } V_{j,k} < V^T_{j,k}$$

$$S_{i,j,k} = G_{j,k} \qquad \text{if } V_{j,k} \geq V^T_{j,k}$$

$$S_{i,j,k} = T_{j,k} + \frac{V_{i,j,k} - T_{j,k}}{V^G_{j,k} - V^T_{j,k}}\left(G_{j,k} - T_{j,k}\right) \text{ if } V^T_{j,k} \leq V_{i,j,k} \leq V^G_{j,k}$$

If goodness decreases with raw value, the equations must be adjusted. Figure 5.2 shows graphically the resulting scoring method for cases in which more is better (solid line) and cases for which more is worse (dashed lines). The order of goal and threshold is reversed for the two cases—for the more-is-worse case (dashed lines), the threshold comes second and the goal first as one reads along the x-axis (see the parenthetical values).

Figure 5.2
Score Versus Raw Value for Goals and Thresholds Methods



Aggregation to Find Measure Scores with Weak Thresholds Method. The score of measure *j* is again given by a linear weighted sum, as in the Goals method, but the submeasure scores are different:

$$M_{i,j} = \frac{\sum_{k=1}^{n_j} W_{j,k} S_{i,j,k}}{\sum_{k=1}^{n_j} W_{j,k} G_{j,k}}$$

Aggregation to Find Overall Effectiveness with Weak Thresholds Method. Overall effectiveness with the Weak Thresholds method is given by a linear weighted sum, as previously, but the measure scores are different:

$$E_i = \frac{\sum_{j=1}^{m} C_j M_{i,j}}{\sum_{j=1}^{m} C_j}$$

Thresholds Method

Submeasure Scores with Thresholds Method. Submeasure scores are calculated with the same function as that used for the Weak Thresholds method:

$$\begin{aligned}
S_{i,j,k} &= 0 && \text{if } V_{j,k} < V^T_{j,k} \\
S_{i,j,k} &= G_{j,k} && \text{if } V_{j,k} \geq V^T_{j,k} \\
S_{i,j,k} &= T_{j,k} + \frac{V_{i,j,k} - T_{j,k}}{V^G_{j,k} - V^T_{j,k}} \left(G_{j,k} - T_{j,k} \right) && \text{if } V^T_{j,k} \leq V_{i,j,k} \leq V^G_{j,k}
\end{aligned}$$

Aggregation to Find Measure Scores with Thresholds Method. The difference in methods occurs here. If any submeasure fails to reach its threshold, the measure is assigned a score of 0:

$$\begin{aligned}
M_{i,j} &= \frac{\sum_{k=1}^{n_j} W_{j,k} S_{i,j,k}}{\sum_{k=1}^{n_j} W_{j,k} G_{j,k}} && \text{if all submeasures reach their thresholds} \\
M_{i,j} &= 0 && \text{otherwise}
\end{aligned}$$

Aggregation to Find Overall Effectiveness with Thresholds Method. Effectiveness is calculated precisely as before, but the measure scores are different:

$$E_i = \frac{\sum_{j=1}^{m} C_j M_{i,j}}{\sum_{j=1}^{m} C_j}$$

Weakest Link Method

The Weakest Link Method is even more stringent in enforcing the "requirements" represented by thresholds.

Submeasure Scores with Weakest Link Method. Submeasure scores are calculated with the same function as for the other threshold methods:

$$\begin{aligned}
&S_{i,j,k} = 0 && \text{if } V_{j,k} < V_{j,k}^{T} \\
&S_{i,j,k} = G_{j,k} && \text{if } V_{j,k} \geq V_{j,k}^{T} \\
&S_{i,j,k} = T_{j,k} + \frac{V_{i,j,k} - T_{j,k}}{V_{j,k}^{G} - V_{j,k}^{T}}\left(G_{j,k} - T_{j,k}\right) && \text{if } V_{j,k}^{T} \leq V_{i,j,k} \leq V_{j,k}^{G}
\end{aligned}$$

Aggregation to Find Measure Scores with Weakest Link Method. With the Weakest Link Method, the measure score is the minimum of the submeasure scores. If any submeasure fails to reach its threshold, the measure score will be 0, as in the Thresholds method, but if all submeasures reach their thresholds, the score will be different from that in the Thresholds method and typically smaller:

$$M_{i,j} = \min_k \left\{ S_{i,j,k} \right\}$$

Aggregation to Find Overall Effectiveness with the Weakest Link Method. Aggregation with the Weakest Link method is performed simply by taking the minimum measure score (which is identical to the minimum submeasure score of all submeasures). If any submeasure in any of the measures fails to reach its threshold, effectiveness will be 0. Even if that does not happen, effectiveness will typically be smaller in this method:

$$E_i = Min_j \left\{ M_{i,j} \right\}$$

Rankings Method

The Rankings method does not use goal or threshold values. Instead, for each submeasure, the investment options are simply ranked from best to worst, without regard to absolute performance. Instead of submeasure and measure scores, we refer to submeasure and measure ranks for this method.

Submeasure Ranks. Let $R_{i,j,k}$ be the rank of investment option *i* for measure *j* and for submeasure *k*. We define it as one more than the number of investment options that perform

strictly better than investment option *i* on submeasure *k* of measure *j*. Thus, if two investment options have the same raw value, they will have the same rank.

Aggregation to Find Measure Ranks with Rankings Method. The aggregation from submeasure rankings to measure rankings is again a linear weighted sum. We calculate the average rank $\overline{R}_{i,j}$ within measure *j* as

$$\overline{R}_{i,j} = \frac{\sum_{k=1}^{n_j} W_{i,j} R_{i,j,k}}{\sum_{k=1}^{n_j} W_{i,k}}$$

The value $\overline{R}_{i,j}$ is used to set the color (one of five shades of blue, as shown in Table 5.4 on p. 64) in the measure-summary table, depending on the quintile in which the average ranking resides.

Aggregation to Find Overall Effectiveness with Rankings Method. This aggregation function is best explained with words and examples. It is entirely different from the functions used in the other methods. For this effectiveness aggregation, each measure is assigned a score based on rankings.

Let us assume that *K* investment options are under consideration and that each submeasure has $K(K-1)/2$ points to distribute among the investment options. If there are no ties for the values in submeasure *j*, the submeasure score is given by

$$R'_{i,j,k} = K - R_{i,j,k}$$

If there are ties, the points that would have gone to the investment options in those positions are combined and then equally distributed among the investment options. For example, with ten investment options, the second- and third-place investment options would receive 8 and 7 points, respectively. If two investment options are tied for second place, they would receive (7+8)/2 = 7.5 points each. This scoring method is used instead of a linear transformation of the rankings to avoid producing artificially large numbers in the case of ties. To illustrate, if each of ten investment options had the same value for a submeasure, they would all tie for first. If the ranking effectiveness score did not take ties into account, each investment option would receive 9 points, meaning that the total (unweighted) contribution to the final score (summed across investment options) by that submeasure would be 90 points. By comparison, for a submeasure where every investment option had a different value, the total (unweighted) contribution to the final score by that submeasure would be 45 points (i.e., 9 + 8 + 7 + 6 + 5 + 4 + 3 + 2 + 1).

As with the other scoring methods, each submeasure $S_{j,k}$ has a weight $W_{j,k}$ in the aggregation to the measure score. Similarly, the weights C_i determine the relative contribution of each measure to the effectiveness score for each investment option. The measure score for an investment option *i* for measure *j* is

$$M_{i,j} = \frac{\sum_{k=1}^{n_j} W_{j,k} R'_{i.j.k}}{\sum_{k=1}^{n_j} (K-1) W_{j,k}}$$

Because the maximum possible value of $\overline{R}_{i,j}$ for each individual submeasure is $K - 1$, the denominator in the above expression scales the effectiveness score to be between 0 and 1. The effectiveness score for each investment option over all measures, denoted E_i, is

$$E_i = \frac{\sum_{j=1}^{m} C_j M_{i,j}}{\sum_{j=1}^{m} C_j}$$

Color-Coding in Scorecards

On scorecards, PAT represents the scores of measures or submeasures by colors (or by a combination of colors and numerical values, if desired). The conventions used for the color-coding are of two types, one for the Thresholds, Weak Thresholds, and Weakest Link methods and one for the Rankings method.

Colors for Thresholds, Weak Thresholds, and Weakest Link Methods

For all the non-Rankings methods used by PAT, the scores of the investment options can be mapped into the colors of familiar stoplight charts, where red is worst and orange, yellow, light green, and green are successively better. A five-color system is used for our measure-summary table, because over the decades, five has proven to be a comfortable number that makes sufficient distinctions but avoids cognitive overload. The mapping for the measure scores is shown in Table 5.3. In addition, for the Thresholds and Weakest Link methods, if any submeasure fails to reach a threshold, the cell in the measure summary may optionally have an F shown in the upper right-hand corner. The convention in PAT is that the score leans upward at boundaries, so that a score of 0.800000 is dark green, whereas a score of 0.799999 is light green.

Colors for Rankings Method

Color-coding on the measure-summary table for the Rankings method is different and even uses different colors, to avoid conveying the impression of good and bad associated with the stoplight charts for the Goals and Thresholds methods.

Table 5.3
Mapping Measure Scores into Colors

Range of Scores	Color
$0 \leq$ score < 0.2	Red
$0.2 \leq$ score < 0.4	Orange
$0.4 \leq$ score < 0.6	Yellow
$0.6 \leq$ score < 0.8	Light green
$0.8 \leq$ score ≤ 1	Dark green

As shown in Table 5.4, the colors go from light blue to dark blue, denoting the quintile in which the weighted average rank of the investment option lies. For example, if there were ten investment options, an investment option would receive the lightest blue color if the weighted average rank was two or lower and would receive the darkest blue color if it was eight or greater. The same coloring method, based on quintiles, is used on the *Drilldown* sheets, where the rankings in each submeasure set the color for the cell.

Table 5.5 summarizes the various methods concisely.

Examples of Scoring and Aggregation Using Different Methods

To provide examples for each scoring method, we look at two measures, M_1 and M_2, each consisting of three submeasures. All submeasures take values between 0 and 10, inclusive, with 2 being the threshold value and 7 being the goal value in each case. For both measures, submeasure $S_{i,3}$ will have weights twice those of the other two submeasures; all submeasures receive a score of 0 for not reaching the threshold value. By setting the weights of the three submeasures to 0.25, 0.25, and 0.5, we get a sum of 1, so there is no need to divide the sum of the submeasure scores by the sum of the weights. We also assume the weights of the measures are equal. We consider three investment options, which we call Investment Options A, B, and C. The raw values for each investment option for each submeasure are given in Table 5.6. (This and subsequent tables in this chapter are not PAT displays, but rather were constructed for the discussion.)

Table 5.4
Color-Coding in the Rankings Method

Meaning	Color
(Average) rank in first quintile	
(Average) rank in second quintile	
(Average) rank in third quintile	
(Average) rank in fourth quintile	
(Average) rank in fifth quintile	

Table 5.5
Summary of Methods

Method	Submeasure Scores	Measure Scores	Overall Effectiveness	Coloring Method	Comment
Goals	0 or 1, depending on whether goal is reached	Linear weighted sum of submeasure scores	Linear weighted sum of measure scores	As in Table 5.3	Simple and common but arguably simple-minded
Weak Thresholds	As in Figure 5.2	Linear weighted sum of submeasure scores	Linear weighted sum of measure scores	As in Table 5.3	May be appropriate if not all submeasures are critical
Thresholds	As in Figure 5.2	Zero if any submeasure fails to reach threshold; otherwise, linear weighted sum of submeasure scores	Linear weighted sum of measure scores	As in Table 5.3	May be appropriate if all submeasures are critical and have firm requirements
Weakest Link	As in Figure 5.2	Minimum of submeasure scores	Minimum of measure scores	As in Table 5.3	May be appropriate if all measures and submeasures are critical and have firm requirements
Rankings	Modified Borda count	Weighted average of ranks for measure-summary table, linear weighted sum of Borda scores for effectiveness	Linear weighted sum of measure scores	As in Table 5.4	May be appropriate if one wishes to avoid discussion of goals and thresholds

Table 5.6
Illustration of Scoring Methods

	Raw Value					
Submeasure	M1	M1	M1	M2	M2	M2
Level 2 measure	M1.1	M1.2	M1.3	M2.1	M2.2	M2.3
Weight	0.25	0.25	0.5	0.25	0.25	0.5
High or Low values desired?	High	High	High	High	High	High
Threshold value	2	2	2	2	2	2
Goal value	7	7	7	7	7	7
Level 2 value for Threshold	0	0	0	0	0	0
Level 2 value for Goal	1	1	1	1	1	1

Goals Method

Table 5.7 presents illustrative results for the Goals method. Values that meet or exceed the goal value are highlighted in green. The table also shows the calculation of the submeasure and measure scores, and the measure-score cell for each measure is colored to correspond to the color scheme that appears on the *Summary* sheet in PAT.

Table 5.7
Illustrative Results for the Goals Method

Measure	M1	M1	M1		M2	M2	M2		
Level 2 measure	M1.1	M1.2	M1.3		M2.1	M2.2	M2.3		
Weight	0.25	0.25	0.5		0.25	0.25	0.5		
High or Low values desired?	High	High	High		High	High	High		
Threshold value	2	2	2		2	2	2		
Goal value	7	7	7		7	7	7		
Level 2 value for Threshold	0	0	0		0	0	0		
Level 2 value for Goal	1	1	1		1	1	1		
				M1 score				M2 score	Effec-tiveness
Option A	10	10	5		5	5	5		
Weighted score	.25	.25	0	.5	0	0	0	0	.25
Option B	7	5	6		8	1	10		
Weighted score	.25	0	0	.25	.25	0	.5	.75	.5
Option C	1	5	10		10	10	10		
Weighted score	0	0	.5	.5	.25	.25	.5	1	.75

Since the weights of the measures are equal, the effectiveness score is just the average of the two measure scores. Although it reaches only one goal in measure M_1, that submeasure is weighted twice as much as the other two, hence it has the same weighted percentage of goals reached as Investment Option A, which reaches two goals in measure M_1.

Thresholds Method

With the Thresholds method, values for measures that meet or exceed the goal value are highlighted in green; values that meet or exceed the threshold value (but not the goal value) are highlighted in yellow; and values that fail to meet the threshold value are highlighted in red (Table 5.8). In addition, we show the calculation of the measure score and effectiveness score and color the summary-score cell for each measure to correspond to the color scheme that appears on the *Summary* sheet in PAT for the Thresholds method. We also show the effectiveness score (assuming the measures have equal weight) for both measures in the rightmost column. In a weighted-score row, a cell containing xxx means that the submeasure failed to reach the threshold value, so the measure score for the entire measure is zero.

If an investment option reaches the goal, the weighted submeasure score is 1 times the submeasure weight. If the raw value is between the threshold and the goal (say, 5), because 5 is 60 percent of the way from the threshold (2) to the goal (7), the unweighted submeasure score would be 0.6, which is then multiplied by the submeasure weight to get the weighted submeasure score. In this case, Investment Option A did not fail to reach any of the threshold values, so it has the highest effectiveness score, even though Investment Option C meets four out of six goals.

Table 5.8
Illustrative Results for the Thresholds Method

Measure	M1	M1	M1		M2	M2	M2		
Level 2 measure	M1.1	M1.2	M1.3		M2.1	M2.2	M2.3		
Weight	0.25	0.25	0.5		0.25	0.25	0.5		
High or Low values desired?	High	High	High		High	High	High		
Threshold value	2	2	2		2	2	2		
Goal value	7	7	7		7	7	7		
Level 2 value for Threshold	0	0	0		0	0	0		
Level 2 value for Goal	1	1	1		1	1	1		
				M1 score				M2 score	Effec-tiveness
Option A	10	10	5		5	5	5		
Weighted score	.25	.25	.3	.8	.15	.15	.3	.6	.7
Option B	7	5	6		8	1	10		
Weighted score	.25	.15	.4	.8	.25	xxx	.5	0	.4
Option C	1	5	10		10	10	10		
Weighted score	xxx	.15	.5	0	.25	.25	.5	1	.5

Weak Thresholds Method

For the Weak Thresholds method, values that meet or exceed the goal value are highlighted in green; those that meet or exceed the threshold value but not the goal value are highlighted in yellow; and those that fail to meet the threshold value are highlighted in red (Table 5.9). We also show the measure score and effectiveness score and color the cells appropriately. We show the effectiveness score (assuming the measures have equal weight) for both measures in the rightmost column. Even though Investment Option C fails for submeasure $S_{1,1}$, reaching the goal value on four of six submeasures pushes its effectiveness above that of the other two options.

Weakest Link Method

For the Weakest Link, values that meet or exceed the goal value are highlighted in green; those that meet or exceed the threshold value but not the goal value are highlighted in yellow; and those that fail to meet the threshold value are highlighted in red (Table 5.10). We also show the (unweighted) submeasure score, the measure score (which is the minimum of the submeasure scores for each measure), and the effectiveness score (which is the minimum of the measure scores) for each investment option. The weights of the submeasures do not apply here. We color the effectiveness score cell for each measure to correspond to the color scheme used in PAT for this method. Because Investment Option A is the only option that did not fail on any submeasure, it has the highest effectiveness score under the Weakest Link method.

Table 5.9
Illustrative Results for the Weak Thresholds Method

Measure	M1	M1	M1		M2	M2	M2		
Level 2 measure	M1.1	M1.2	M1.3		M2.1	M2.2	M2.3		
Weight	0.25	0.25	0.5		0.25	0.25	0.5		
High or Low values desired?	High	High	High		High	High	High		
Threshold value	2	2	2		2	2	2		
Goal value	7	7	7		7	7	7		
Level 2 value for Threshold	0	0	0		0	0	0		
Level 2 value for Goal	1	1	1		1	1	1		
				M1 score				M2 score	Effec-tiveness
Option A	10	10	5		5	5	5		
Weighted score	.25	.25	.3	.8	.15	.15	.3	.6	.7
Option B	7	5	6		8	1	10		
Weighted score	.25	.15	.4	.8	.25	0	.5	.75	.4
Option C	1	5	10		10	10	10		
Weighted score	0	.15	.5	.65	.25	.25	.5	1	.83

Table 5.10
Illustrative Results for the Weakest Link Method

Measure	M1	M1	M1		M2	M2	M2		
Level 2 measure	M1.1	M1.2	M1.3		M2.1	M2.2	M2.3		
Weight	0.25	0.25	0.5		0.25	0.25	0.5		
High or Low values desired?	High	High	High		High	High	High		
Threshold value	2	2	2		2	2	2		
Goal Value	7	7	7		7	7	7		
Level 2 value for Threshold	0	0	0		0	0	0		
Level 2 value for Goal	1	1	1		1	1	1		
				M1 score				M2 score	Effec-tiveness
Option A	10	10	5		5	5	5		
Weighted score	1	1	.6	.6	.4	.4	.4	.4	.4
Option B	7	5	6		8	1	10		
Weighted score	1	.4	.6	.4	1	0	1	0	0
Option C	1	5	10		10	10	10		
Weighted score	0	.4	1	0	1	1	1	1	0

Rankings Method

In our example, the summary and effectiveness weights are identical (with the third submeasures of each measure having twice the weight of the other two), as shown in Table 5.11.

The average rank- and measure-score calculations are compressed slightly, and all values are rounded to two decimal places. For the measure score, the sum of the submeasure scores is divided by the product of the maximum submeasure score per measure (2) and the sum of the weights (1). The effectiveness value is just the average of the measure scores. Because Investment Option C has the best value for four of six submeasures, it is clearly the best option under the Rankings method.

Table 5.11
Illustrative Results for the Rankings Method

Measure	M1	M1	M1		M2	M2	M2		
Level 2 measure	M1.1	M1.2	M1.3		M2.1	M2.2	M2.3		
Weight	0.25	0.25	0.5		0.25	0.25	0.5		
High or Low values desired?	High	High	High		High	High	High		
Threshold value	2	2	2		2	2	2		
Goal value	7	7	7		7	7	7		
Level 2 value for Threshold	0	0	0		0	0	0		
Level 2 value for Goal	1	1	1		1	1	1		
				Avg. rank				Avg. rank	Effectiveness
Option A	10	10	5		5	5	5		
(rank)x(weight)	.25	.25	1.5	2	.75	.5	1.5	2.75	
(score)x(weight)	.5	.5	0	.5	0	.25	0	.13	.32
Option B	7	5	6		8	1	10		
(rank)x(weight)	.5	.5	1	2	.5	.75	.5	1.75	
(score)x(weight)	1	.125	.5	.44	.25	0	1	.63	.54
Option C	1	5	10		10	10	10		
(rank)x(weight)	.75	.5	.5	1.75	.25	.25	.5	1	
(score)x(weight)	.25	.125	1	.69	.5	.5	1	1	.85

CHAPTER SIX

Marginal and Chunky Marginal Analysis

Introduction

In marginal analysis, small changes to key variables in a system are considered one at a time. Marginal analysis is often used to find which variables are most responsible for affecting the outcomes of a system. When the key variables are investments, marginal analysis helps to determine what "the next dollar" (or million dollars) should be allocated to (or removed from) in order to maximize the capability of the resulting collection of investments. Ideally, the small changes in each variable are equivalent in magnitude, to enable relevant comparisons between options. Although marginal analysis can be used for a variety of systems, we restrict our discussion to the marginal analysis of investments.

Marginal analysis is not appropriate for all situations. For example, small deviations in investments may have no effect on system outputs. This happens particularly when investments are tied to purchases of discrete objects. An extra dollar invested in the acquisition of a radar system has absolutely no impact when a single component costs thousands or millions of dollars. Similarly, investments in systems that require a large buy-in before they become effective have no impact until the buy-in is reached, at which point there may be a large discontinuity in capability.

Conversely, small deviations in investments may have a disproportionate effect on the outputs of the system. A budget that includes 90 percent of the cost to acquire a missile does not get the investor 90 percent of a missile. For the most part, small reductions in investment do not lead to proportionate reductions in system capability.

Marginal analysis tends to be more meaningful when the options that result from constant deductions to each investment are really of equal value. Consider a situation in which \$16 million is spent to acquire three different types of missiles, where each individual missile costs \$1 million. Assume further that the current investment plan purchases one missile of the first type, five of the second type, and ten of the third type. Three equal-cost investment options that could result from a \$1 million cut in funding correspond to not purchasing one missile of each type. In contrast, consider a situation where \$16 million is spent in the acquisition of three missiles, one costing \$1 million, one costing \$5 million, and one costing \$10 million. A cut of \$1 million from any of the three missile purchases results in not getting any missiles, so this cut actually results in comparing three cases costing \$6 million, \$11 million, and \$15 million for the acquisition of two of the three types of missiles.

This suggests a variant of marginal analysis in which the changes to the current set of investments represent the removal (or addition) of whole purchases. As with marginal analysis, these purchases are removed individually from the current investment, with each possible

removal defining a new investment option. The costs of the resulting investment cases provide another measure that can be used as a basis for comparison. The important question is often not, "Where do we spend the next dollar?" but rather, "How do we invest this extra $50 million?" (Pessimists or realists will suggest that the question asked more often is, "How do we handle this $50 million budget cut?") This *chunky* marginal analysis method will be described in more detail below, as will the application of PAT to assist with this analysis.

Chunky Marginal Analysis for a Ballistic Missile Defense Example

We consider as a base case a fixed collection of ballistic-missile defense system (BMDS) investments over time in both R&D and acquisitions. We generate a collection of investment options by considering variations from the base case. These steps are large-scale additions to (or subtractions from) the base case. Some examples would be the cancellation of R&D on a particular program, or a reduced (or increased) acquisition of a radar system or interceptor. The steps should not be so small that it is impossible to discern the base case from the BMDS associated with the new investment option, but they should not be so large that one could be decomposed into a collection of smaller, meaningful steps. Thus, a step should not consist of the cancellation of three unrelated programs; rather, three new options should be defined by the cancellation of each individual program. In addition, a step should be maximal in the sense that any program that is made unnecessary (or necessary) by the cancellation (or addition) of one program should also be cut (or included) along with that program. For example, cutting the development of a radar platform should also cut the development of any battle-management suite associated with that radar platform (unless the suite can also be used for other radar systems under development).

Once these steps are defined, each investment option consists of the base case and one (or more) of these steps. As the number of steps increases, the number of possible investment options increases exponentially. It may be best to restrict analysis to options that are at most a fixed number of steps away from the base case. With n possible steps, there are roughly $n^2/2$ options that are at most two steps away from the base case and about $n^3/6$ options that are at most three steps away from the base case. The number of investment options under consideration should also be tempered by the ability to determine the costs associated with each, as well as the ability to analyze the BMDS that results from each. PAT can store thousands of investment cases and can display some or all of those cases on its output sheets.

The output sheet that is perhaps most useful in assisting with chunky marginal analysis is the *Scatter Plot*, where the user can select the x-axis from a collection of cost metrics (over various time periods, constrained to R&D investment or deployment investment only, etc.) and the y-axis from two different evaluation metrics. Investment options are plotted on the display as points of different colors (and different shapes if more than one measure is displayed on the y-axis). This is particularly useful in determining which investment option is best (and the corresponding programs that should be cut) if the budget is reduced from the base case.

Consider a notional example of a base case that consists of investments in three options (called "engagement sequence groups" at MDA): one boost phase, one midcourse phase, and one terminal phase (based in the United States). There are three obvious steps away from this base case: the cancellation of programs specific to each phase of the defense (in general, defense systems from different phases may share tracking systems, so a cut of a particular phase of the

defense does not necessarily eliminate all programs associated with that phase). Because the number of steps is so small, there is no reason to not consider the eight investment options corresponding to all the subsets of the phases that can be implemented.

Next, consider the following probabilities for engagement with a single attacker shown in Table 6.1 for four different scenarios: homeland defense (HD), homeland defense with no boost-phase access, homeland defense with advanced countermeasures (CMs), and defense of deployed forces and defense of friends and allies (DODF/DOFA).

Assuming that the performances of the systems in each phase are independent of one another, we can compute the probability that a single missile is intercepted for each of the eight investment options, as well as for each of the four scenarios, which can be thought of as measures. If we set a threshold of 0.5 and a goal value of 0.8 for each scenario, we get the results shown in Table 6.2 (the colors that would appear on the *Drilldown* sheet) under the default (goal-based with thresholds) scoring method.

Treating the individual scenarios as measures (or, to be accurate, treating each column as a measure consisting of a single submeasure), we can calculate the effectiveness of each investment option for the Thresholds scoring method. Assuming all scenarios are equally weighted, with a submeasure score of 0.5 for reaching the threshold value and 1 for reaching the goal value, the effectiveness score of each investment option is as shown in Table 6.3.

Table 6.1
Notional Probabilities of Intercept for Illustrative Problem

	Mission Case				
Flight Phase	**HD**	**No Boost Phase**	**Advanced CMs**	**DODF/DOFA**	**Cost ($ billions)**
Boost (B)	0.7	0.0	0.5	0.7	9
Midcourse (M)	0.6	0.6	0.4	0.6	6
Terminal (T)	0.5	0.5	0.3	0.0	3

Table 6.2
Performance of Options (Probabilities of Intercept) by Mission

Mission or Cost Option	HD	No Boost Phase	Advanced CMs	DODF/DOFA	Cost ($ billions)
B + M + T	0.94	0.8	0.79	0.88	18
B + M	0.88	0.6	0.7	0.88	15
B + T	0.85	0.5	0.65	0.7	12
M + T	0.8	0.8	0.58	0.6	9
B only	0.7	0.0	0.5	0.7	9
M only	0.6	0.6	0.4	0.6	6
T only	0.5	0.5	0.3	0	3
None	0	0	0	0	0

Table 6.3
Costs and Effectiveness Comparisons: Equal Emphasis on all Scenarios

Mission or Cost Option	HD	No Boost Phase	Advanced CMs	DODF/ DOFA	Eff. (Sum/4)	Cost ($ billions)
B + M + T	0.94 [1]	0.8 [1]	0.79 [0.98]	0.88 [1]	1.0	18
B + M	0.88 [1]	0.6 [0.67]	0.7 [0.83]	0.88 [1]	0.88	15
B + T	0.85 [1]	0.5 [0.5]	0.65 [0.75]	0.7 [0.83]	0.77	12
M + T	0.8 [1]	0.8 [1]	0.58 [0.64]	0.6 [0.67]	0.7	9
B only	0.7 [0.83]	0.0 [0]	0.5 [0.5]	0.7 [0.83]	0.54	9
M only	0.6 [0.67]	0.6 [0.67]	0.4 [0]	0.6 [0.67]	0.5	6
T only	0.5 [0.5]	0.5 [0.5]	0.3 [0]	0 [0]	0.25	3
None	0 [0]	0 [0]	0 [0]	0 [0]	0	0

NOTE: The unbracketed numbers are probabilities of successful intercept, as in Table 6.2. The numbers within brackets are the effectiveness scores using the Thresholds method.

Another possible perspective would be to put a greater emphasis on dealing with a peer threat that can deny boost-phase access and implement advanced countermeasures. We can examine that case by weighting those two scenarios twice as much as the other two. The effectiveness of each investment option is then as shown in Table 6.4.

The *Scatter Plot* sheet can display the effectiveness of each investment case for both perspectives, with the cost of the investment option as the x-axis (Figure 6.1).

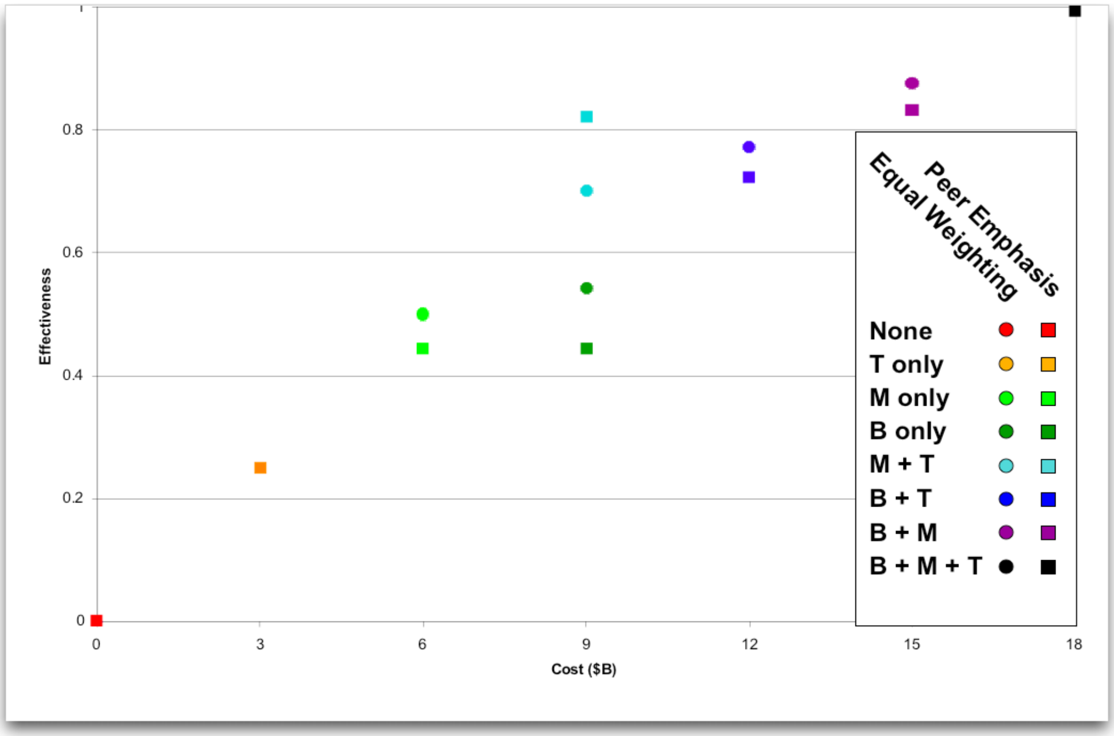
The scatter plot view permits straightforward comparison of the investment options under both perspectives. Reading the scatter plot, however, requires some instruction, because it is unconventional. Suppose that the budget must be cut from $18 billion to $9 billion. At that budget level (x-axis), we see that the best option by the first perspective (squares) is M + T (elimination of boost phase). That is, the topmost square has the color associated with the M + T option in the legend box at the right. When PAT is being used live, the square can be identified by merely mousing over it and seeing its name pop up.

Table 6.4
Costs and Effectiveness Comparisons: Extra Emphasis on Peer Threat

Mission or Cost Option	HD	No Boost Phase	Advanced CMs	DODF/ DOFA	Scaled Eff. (Sum/6)	Cost ($ billions)
B + M + T	0.94 [1]	0.8 [2]	0.79 [1.96]	0.88 [1]	0.99	18
B + M	0.88 [1]	0.6 [1.33]	0.7 [1.67]	0.88 [1]	0.83	15
B + T	0.85 [1]	0.5 [1]	0.65 [1.5]	0.7 [0.83]	0.72	12
M + T	0.8 [1]	0.8 [2]	0.58 [1.28]	0.6 [0.67]	0.82	9
B only	0.7 [0.83]	0.0 [0]	0.5 [1]	0.7 [0.83]	0.44	9
M only	0.6 [0.67]	0.6 [1.33]	0.4 [0]	0.6 [0.67]	0.44	6
T only	0.5 [0.5]	0.5 [1]	0.3 [0]	0 [0]	0.25	3
None	0 [0]	0 [0]	0 [0]	0 [0]	0	0

NOTE: The unbracketed numbers are probabilities of successful intercept, as in Table 6.2. The numbers within brackets are the effectiveness scores using the Thresholds method.

Figure 6.1
Cost-Effectiveness Comparisons for Two Perspectives



But what if we are more concerned about the peer threat to the homeland? Here, the circles indicate the effectiveness of each investment option, and in this case, the same investment option is best. That certainly might not have been the case, as can be seen, for example, by reading the chart for budget cuts of $3 billion, $6 billion, and $9 billion and then comparing the results to what follows.

In this contrived example, the terminal-phase, midcourse-phase, and boost-phase options should be canceled for the budget cuts of $3 billion, $6 billion, and $9 billion, respectively, to maintain the greatest effectiveness for the equal-weighting perspective. Although the boost-phase option costs as much as retaining the midcourse-phase and terminal-phase options, the capability is much lower. This is particularly amplified under the peer-emphasis perspective (the squares) when the effectiveness score of the midcourse-only and the boost-phase-only options are nearly equivalent. For budget cuts between $3 billion and $9 billion, cancellation of the boost-phase option has greater effectiveness than cancellation of the less-expensive midcourse-phase option under the peer-emphasis perspective. Thus, depending on the perspective chosen, different priorities are placed on the retention of different phases of the defense.

CHAPTER SEVEN

Concluding Observations

Purpose and Function of PAT

As described, from the outset, PAT is an "empty-vessel" tool, not a model. Its purpose is to help frame, manipulate, analyze, and present results of multifaceted information to decisionmakers, particularly those concerned with strategic-level planning. For defense, this would include what are sometimes called force planning, mission-level capabilities planning, and cross-capability-area planning. PAT is designed to work in parallel with appropriate capabilities models[1] and to make use of diverse other information, such as structured expert judgment. PAT can accommodate very different management purposes, including highlighting problems to be confronted, emphasizing accomplishments rather than residual shortcomings, and making the relatively soft and forgiving assessments that are common in broad balance-of-power studies.

Seeking Flexibility, Adaptiveness, and Robustness

Some who hear of PAT for the first time may think of using it to optimize resource allocation mathematically. They may see the mechanism for calculating cost-effectiveness and assume that the objective is—or should be—to maximize that quantity. That would be a misreading of our intentions, and indeed of the philosophy underlying our approach. The most important outputs of PAT are (1) the portfolio-style scorecards in which alternative investment options are assessed simultaneously by a number of very different measures and costs and (2) the next layer of scorecard detail to which the viewer is able to drill down to understand the basis of the color-coded summary assessments and to change higher-level assumptions or priorities that affect those assessments.

Further aggregation to a single number, as in cost-effectiveness calculations, should be deferred to a kind of refinement stage, a stage in which one is "tidying" and thinking about communicating the results of decisions. We recommend this because the cost-effectiveness

[1] A "capabilities model" is a relatively aggregate-level depiction of capability that has attributes such as comprehensibility and parameterization that permit exploratory analysis under uncertainty. Such models differ from, e.g., the high-resolution, high-fidelity simulation models used for training and mission rehearsal. In some cases, they can be "formula models" or simple programs suitable for a single analyst to use on his personal computer. In other cases, e.g., the more agile and comprehensible campaign models used by DoD for defense planning, they are somewhat more complicated. Thunder, STORM, and JICM are capability models of this type. JWARS is not, nor are models such as Brawler. Within the emerging realm of models for irregular warfare, the often-mentioned models (e.g., PSOM, SEAS, COMPOEX) are much more complicated, although they have modules that are analogous to capability models.

calculations depend sensitively on the assumptions and priorities that go into them, which are precisely what decisionmakers are paid to think about and decide on. The decisionmakers are responsible for worrying about, say, the "balance" of a portfolio across missions, the extent of risk to be taken, and the ways in which risk can be managed. Therefore, they need to reason at the portfolio level, not at the level where they are merely comparing cost-effectiveness numbers.

PAT provides a number of ways to assess alternatives and some useful, albeit limited, mechanisms for exploring the consequences of alternative assumptions and priorities, but that is very different from optimization. The purpose is to find strategies that enjoy "FARness" (flexibility, adaptiveness, and robustness) within plausible budgets.[2]

PAT as Software

PAT is not industrial-strength software; rather, it is a tool for relatively sophisticated analysts who worry more about functionality than about cosmetics. It has been tested in a number of applications, but it undoubtedly has residual problems. Users are encouraged to contact PAT's developer, Paul Dreyer, at dreyer@rand.org if they discover mistakes or have technical questions about PAT.

PAT checks for most mistakes that users make (for example, entering an investment option or measure in the *Summary* table that does not exist on a data sheet). However, PAT has not been exhaustively tested or "gorilla-proofed," nor has it been refined in the manner of commercial software. Neither the authors nor RAND offers any guarantees or warranties on its use. *We encourage users to keep a clean copy of the PAT template available in the unlikely event that something occurs to make the software unusable.*

The proper use of PAT also requires discipline. We have attempted to simplify much of the initial setup of a portfolio view in the *Template Builder* sheet, but other operations require consistency. For example, if one edits the values on a *Drilldown* sheet, it is necessary to click on the Modify Data Entries button to make those changes propagate through the rest of the tool. Similarly, unless the Auto-Update Chart checkbox is checked on each sheet, the *Scatter Plot* sheet and the *Spider Chart* sheet do not automatically update to reflect changes that have been made to the data sheets; it is necessary to click on the Generate Scatter Plot and Generate Spider Chart buttons on the applicable sheets to see how the changes in the data have affected the outputs.[3]

PAT allows considerable flexibility in what can be changed without having to regenerate the portfolio view, as described above. Weights of measures and submeasures, threshold and goal values, scoring methods, and data values can be changed easily.

The only constraint on the numbers of investment options, measures and submeasures, etc., that can be used is the ability of a spreadsheet to hold all of the input data. That should not be constraining in practice.

The Importance of the Measures and Methods

As with all scorecard methods, considerable care must be taken in the development of the measure/submeasure structure for any analysis performed with PAT. Similar care should be taken with the selection of the scoring method and the parameters and weights for the scoring func-

---

[2] This emphasis in RAND work has been articulated in a number of RAND monographs (Davis, 1994; Davis, 2002a). It was also highlighted in a recent National Academy study (National Research Council, 2006).

[3] As PAT is continuously improved, more automatic updating is being introduced.

tions and effectiveness calculations. If PAT used only linear weighted sums, the methodology would be simpler but less satisfactory for system analysis.

Although we cannot itemize here all the considerations that an analyst should have in mind, a few are particularly worth mentioning, if only as a partial checklist:

- Measures and submeasures should provide an adequately complete assessment.
- Ideally, measures would be independent, and the submeasures of each measure would be independent. When that is not appropriate—i.e., when correlations exist—weighting factors should be chosen so as to avoid results being overly sensitive to a single underlying issue.[4]
- The choice of scoring and aggregation methods merits particular thought. If all of a measure's submeasures are individually critical, then the Threshold method may be called for. If all of the measures are also individually critical, then the Weakest Link Method may be appropriate. If these conditions do not apply, however, and one is more interested in seeing progress than in flagging problems, then the Goals method may be appropriate. The Rankings method can be helpful when, for one reason or another, it is inappropriate to discuss goals and thresholds.
- In any case, it is essential to plan for systematic exploration of how assumptions on the above matters affect both results and perceptions, and to tune assumptions so as to provide a set of baseline results that are as robust as possible. For example, it serves decision-makers poorly when color-coded conclusions change markedly if some low-level assumptions are changed slightly (e.g., moving a goal from 0.89 to 0.9 should not change results dramatically).
- A consequence of the above admonition is that goals and thresholds need to be seen as heuristics, not as absolutes to be accepted mindlessly.

Finally, we note that many of these issues are generic. There is a considerable literature dealing with multiattribute measures and objectives that discusses approaches to weighting these measures, obtaining utilities from individuals or groups, and the use of other aggregation rules.[5]

Next Steps

Over time, PAT will be improved and enhanced, building on the experience of applications. Suggestions will be appreciated. In addition to correcting errors and improving user-friendliness, we are currently thinking about at least the following possibilities for enhancement:

- Permitting different scoring and aggregation methods to be used for different measures or for calculation of cost-effectiveness rather than measure scores.

---

[4] For example, an option could be made to look better by piling on a number of measures, each of which is driven by something accomplished well by the option. Similarly, an option may appear worse than it probably should if the measures chosen reflect a pure worst-case perspective.

[5] Some of these approaches appear under discussions of multiattribute utility theory (Keeney and Raifa, 1976; Kirkwood, 1997), value-focused thinking (Keeney, 1992; Parnell, 2006), and balanced-scorecard methods used in business (Kaplan and Norton, 1996). The original DynaRank documentation also includes some discussion of these approaches (Hillestad and Davis, 1998).

- Providing the ability to generate the measure of cost used in cost-effectiveness as a linear weighted sum of the various costs provided as inputs.
- Developing a richer and more structured mechanism for exploratory analysis, probably building on the alternative-perspectives mechanism. This could include limited mechanisms for search (e.g., finding the combinations of key parameters that would cause a particular option to be assessed well or poorly).

APPENDIX A

Quickstart on Using PAT

This appendix is written for those who want to learn by doing, at least initially. It assumes that the reader has a copy of the relevant Excel file for PAT. The format is informal. The example is the one used in the main text.

Opening PAT

When you open PAT, you may be asked whether to enable macros. If you are asked, the answer is Yes. If the computer refuses to open the file for security reasons, you will need to reset the level of protection:

- Close and reopen Excel
- Go to the top-of-window menu Tools/Macro/Security
- Set security level to "medium."

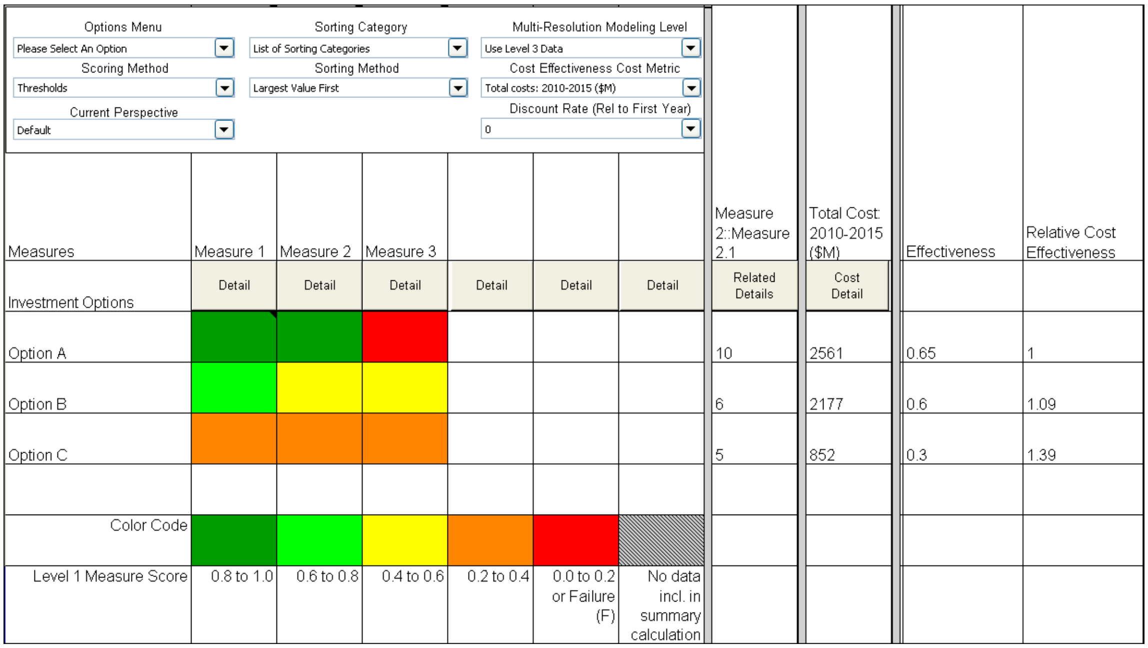
You will now be permitted to continue.[1]

Navigation and Manipulation

To begin, PAT will open a *Summary* sheet (Figure A.1) with some placeholder data, which you will replace. Although you will seldom work with the entire *Summary* sheet at a given time, you should be aware that—as shown in the figure—it has four different vertical blocks of information. The leftmost block is the scorecard that characterizes options by different measures of effectiveness (measures). The second block is a set of columns that allow the user to show selected data, by option, from the second level of detail. The third block contains selected output cost information. The final (rightmost) block contains calculations of the options' effectiveness and cost-effectiveness when aggregated across all of the measures. Ordinarily, the user will focus on the scorecard portion of the *Summary* sheet.

[1] This instruction is for users of Excel in Microsoft Office 2003 for Windows XP. You may not encounter any such warning if you are using Excel 2004 for the Macintosh. The procedure for adjusting the security settings is slightly different in Excel 2007 because of changes in the interface.

Figure A.1
Overview of Summary Sheet



If you are looking at the *Summary* sheet on a computer, note along the bottom of the window that the Summary tab is highlighted. You can switch among sheets by clicking other tabs. Since there are many such tabs, it is often easier to use the Go To Sheet menu item at the top of your screen. Custom sheets will not be listed (e.g., sheets for notes or for specialized cost calculations not done by PAT, or a miniature capabilities model that can generate data entries for PAT's primary sheets).

On the *Summary* sheet, mousing over (dragging the cursor over) the various menus' arrows reveals the following:

- The Options menu contains miscellaneous controls, such as whether to show relative weights and whether to change coloring scheme. You can select the change in coloring scheme to see what happens; repeat four times to get back to where you started.
- Scoring Method allows you to select a scoring method, as discussed in the text. Thresholds is the default method. That is equivalent to linear weighted sums if the thresholds and goals are set to 0 and 1, respectively. An important alternative is the Weakest Link method, i.e., when a score should be no better than the weakest of its contributors.
- The Current Perspective menu allows you to choose from among various perspectives that you have previously defined or to make new ones. A perspective is characterized by its weighting schemes and other parameters. There are none at the outset.
- Sorting Category and Sorting Method allow you to select a column and then sort rows based on some criterion. This is discussed in Dreyer and Davis (2005), although some details have changed.
- Multi-Resolution Modeling Level gives you a choice of which of three databases to use. The option of entering information at a higher level is part of a multiresolution modeling philosophy. Use Level 3 Data actually means enter data at Level 3 and Level 2. Use

MRM Level 2 Data means enter data *only* at Level 2. Use MRM Level 1 Data means enter data *only* at Level 1, essentially specifying answers as you might when experimenting with story line and displays. If you want to do a first, rough-cut analysis, start with Level 2.

- Cost Effectiveness Cost Metric is self-evident, referring to the cost that is to be used when evaluating relative cost-effectiveness by dividing effectiveness by a cost. The options on the menu depend on what you specify for costing options in the *Template Builder* or the *Cost Data* sheet, both of which are described later.
- Discount Rate gives you the option of doing present-value calculations by selecting the real discount rate, assuming that the options' costs are already in constant dollars. If they are in current dollars, you would use a discount rate equal to inflation plus the real discount rate.

The illustrative *Summary* sheet's first column should be read as Investment Options. The word "Measures" pertains to the subsequent columns in row 1. The phrase "Level 1" is present temporarily and is later replaced by the name of the first Level 1 measure.

Subsequent columns that contain Detail buttons are reserved for potential measures of the options' goodness or utility. As suggested by Figure A.1, if you scroll to the right you will encounter a block of columns reserved for cost information. Which cost columns appear here depends on information entered elsewhere. You might have columns for, say, R&D, acquisition, and O&S, as well as total costs in a particular period, etc.

Continue scrolling and you will find columns to the right that are reserved for net effectiveness and relative cost-effectiveness. Those show up only after relevant options and data have been entered.

The Detail buttons allow you to drill down to a second level of detail, one that "explains" the summary-level results for the column in question.

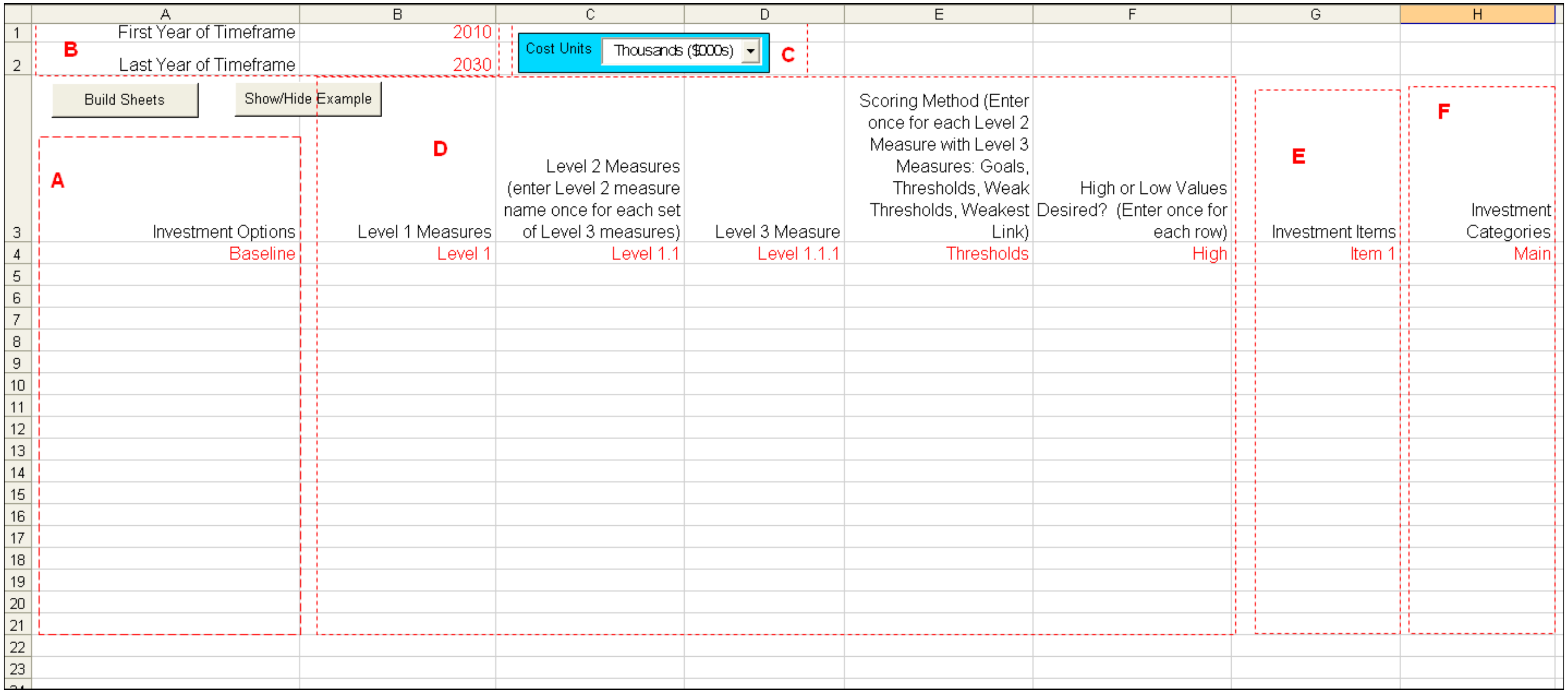
Template Builder

Template Builder's Structure

Go next to the *Template Builder* sheet (at the far right of the tabs or via Go To Sheet/Inputs). This is where you enter the information that dictates the overall structure of your portfolio analysis. Figure A.2 shows *Template Builder*'s structure. The various blocks in dashed-edge red rectangles are independent. That is, do not assume that two items relate to each other just because they are in adjacent columns. Items in a given block relate to each other. This is what you have to do for each block (the red text items are placeholders):

- Fill in the names of your options, one line per option. "Baseline" is the placeholder example.
- Indicate the range of years that you wish to consider (2010–2030 in the example).
- Define the units of currency ("Thousands" in the example, although that surely doesn't apply to government).
- Enter the names of Level 1, Level 2, and Level 3 measures, along with some control parameters for the latter. This is a large and relatively complicated block.

Figure A.2
Illustrative Template Builder Sheet



- List the items for which you want to track costs separately (Item 1 in the example). This could be, e.g., ships, airplanes, . . . ; or radars, interceptors, . . . ; or human capital, equipment, ... A word of caution: If you have numerous items here, the data requirements quickly become very burdensome. If you don't want to bother, you might replace "Item 1" with "Stuff" or "Miscellaneous."
- List the investment "categories" for which you want to track costs separately ("Main" is the placeholder). The usual choices here might be "Total" (meaning don't bother with categories) or, e.g., the items "R&D," "acquisition," and "O&S."

Blocks A, B, and C require little explanation, but let us elaborate on Block D. The syntax for entering data in the first three columns is shown in Table A.1. We assume here that you have three measures, as in the text, with only the second measure having third-level data. Measure 1.1 appears to the immediate right of Measure 1, and Measure 2.2.1 appears to the immediate right of Measure 2.2. The name of a measure should not be repeated if the next row is simply filling in a submeasure.

You, of course, will want to have more interesting names for your various measures and submeasures. The following are some examples of the kinds of measures you might use at the first, second, and third levels of detail (separated by semicolons):[2]

Force Structure: Regions of the World. Within each, environment-shaping versus warfighting; within warfighting, expectations for different test cases. Additional measures could be added for risks of various types at each level of analysis.

Acquisition of Weapon Systems. Broad mission classes; within each, suitable test scenarios; within each, suitable technical measures (e.g., probability of being able to penetrate air defenses).

International Business. Operating divisions; measures of performance in each operating division; diagnostic measures to explain performance.

Planning of Staff for a Knowledge-Industry Business. Business areas; within each, core expertise (leadership), quality, number, diversity, and affordability of staff mix; within, say, the measure of quality, various diagnostics such as experience, highest degree (or equivalent), specialty experience in the business area, and past performance.

Table A.1
Format for Entering Measure Names in Template Builder

Measure 1	Measure 1.1	
	Measure 1.2	
Measure 2	Measure 2.1	
	Measure 2.2	Measure 2.2.1
		Measure 2.2.2
Measure 3	Measure 3.1	
	Measure 3.2	

[2] For some actual examples from past studies, see Davis, Kugler, and Hillestad (1997), Davis, Shaver, and Beck (2008), and Davis et al. (2008).

None of the above is to be taken literally. The examples are merely starting points.

If you click on the Show/Hide Example button, an example will pop up with entries very similar to those used for the example in the main text. Click the button again to hide the example.

Reviewing Your Template Builder Sheet

Review your sheet carefully to make sure that there are no inappropriate blanks and that syntax is exactly as in the examples. This is where most errors occur in building PAT worksheets. For example, the word Threshold may not appear in the last row listing the measures and submeasures because you added one and forgot to fill in that column. If all looks well, click Build Sheets (top left corner).

You will be prompted about whether you want to save data. If you are starting fresh, the answer is No, but if you are rerunning *Template Builder* to reflect some changes in the middle of a project, you may want to save the data. In fact, you will be saving only the data associated with options and measures that still have the same names in the new structure, but that may be quite a lot.

Once *Template Builder* has stopped running, go to the *Summary* sheet. Select Update Summary from the Options menu, and the *Summary* will be generated. You should then see the desired structure of headers. Check carefully; some error may have occurred, in which case you may not see all the option names or all the top-level measures. Click on the Detail buttons to see whether the Level 2 structures are correct. Then click on the Level 3 Drilldown tab to see whether the appropriate Level 3 measures (if any) are available from the menu box at the top left (Level 3 Drilldown Options).

Data Entry

Chapter Three presents completed examples of all the data-entry sheets, so we will be brief here.

Let us assume that you want to use Level 2 and Level 3 data, rather than the MRM options, in which you enter data only at Level 2 or Level 1. Go to the *Level 3 Data* sheet (via the tab or the Go To Sheet menu). (See Chapter Three for a filled-out example.)

Enter weights for the different Level 3 measures in the fourth row. These might be, e.g., 4 and 2, in which case PAT will normalize them as necessary. Instead, you could have entered 2/3 and 1/3. For the example, however, you can use 1 and 1.

Rows five through eight tell PAT how to handle the data. Since we want high values, we might set the values at 0 and 10 for rows five and six—meaning that the data entered will be between 0 and 10, inclusive. However, you will then want 0 and 1 in rows nine and ten, so that PAT will rescale to that range. If you had specified that "good" was "low," you would reverse the values in rows five and six. Had you chosen something other than Thresholds, the procedure might be slightly different.

Now enter data in the 0-to-10 range for your options.

When you are done, click on Modify Level 2 Data (top left). Select Yes about updating.

You will now be taken to the *Level 2 Data* sheet, where you should fill in data in the same way; some data (in italics) will already be filled in, the result of the Level 3 calculation. Do not type in these cells, obviously, or you will be overwriting the calculations. You might want to

do that for some reason, but remember that any of a number of operations with PAT will cause recalculation, in which case your overwrites will be overwritten! If you really want to "think" at Level 2, you should be using the optional Level 2 MRM approach.

Note: Enter 0 and 1 as the values for Threshold Value and Goal for the columns of values calculated from Level 3, since PAT has generated numbers assuming this result.

When you are done entering data, click Modify Summary (top left). You will be taken to the *Summary* sheet, where you should see the colorful scorecard display.

Costs

Next, you need to enter costs for the options. Do this in the *Cost Data* sheet. It will have a structure corresponding to the number of years that you specified in *Template Builder*. You need to enter costs by year, by option, for each category of investment, and for each type of investment item, which may simply be "none" as in the example. To save trouble at this point, you can enter all the costs in the cells for 2010. Or you could go back to *Template Builder* and start over again with only a single category, "Total," and a single item, "Stuff."

The default is that the costs are in $ millions. Once you're done, click Modify Summary.

Cost-Effectiveness

You will be taken back to the *Summary* sheet. If you scroll far enough to the right, you will see columns with the costs, an effectiveness measure, and relative cost-effectiveness. The effectiveness is merely a linear weighted sum over the various measures, using weights that you specified in the Level 2 data. To see those weights, toggle the corresponding control in the Options menu. You can actually change the weights here as well, although their proper place for change is in the *Level 2 Data* sheet.

Scatter Plot

PAT has many displays, one of which is the scatter plot. To access it, go to the Scatter Plot tab. It will probably be blank. If it is, click on Generate Scatterplot. You will now see each option represented by a dot at a point in the scatter plot corresponding to its effectiveness and cost. Such cost-effectiveness landscapes are good for understanding cost and effectiveness together. They are much better than working only with the ratio of effectiveness/cost. However, remember that the effectiveness calculation depends on the weights given to the measures and—in this simple example—on the assumption of linear weighted sums.

An Exercise

To conclude this Quick-Start material, we provide an exercise for you.

In this exercise, you want to use PAT to compare a baseline option (Option 1) with four alternatives (2, 3, 4, and 5). Suppose you want to assess them in terms of their effectiveness

in two scenarios, A and B, and a catch-all category of "Other" (in national-security work this might include something like "Shaping the Environment"). In characterizing effectiveness, you distinguish between results using "best-estimate" assumptions, best-case assumptions (a measure of upside potential), and worst-case assumptions (a measure of risk). In evaluating the worst-case effectiveness for Scenario B, you feel that it is necessary to consider several "bad" variants of Scenario B which stress capabilities in different ways. They are called variants B.1, B.2, and B.3.

Assuming that all these measures have been appropriately defined and put on the same scale (from 0 to 1), you might have the following data sets, where larger numbers are always better for the measures and where you need not worry about subtleties such as thresholds and ceilings. The data in Tables A.2 through A.4 may be based on studies that used organization-approved models and data sets for the scenarios. Some translation must have been made between outputs of models and the scores shown for the options, but we will not concern ourselves about that here.

Table A.2
Level 2 Data for Illustrative Exercise

Option	Best-Estimate Case	Best Case	Worst Case
	Scenario A		
1 (Base)	0.1	0.1	0.1
2	0.5	0.6	0.3
3	0.55	0.7	0.5
4	0.57	0.9	0.5
5	1	1	0.5
	Scenario B		
1 (Base)	0.1	0.1	Calculated
2	0.41	0.55	Calculated
3	0.45	0.7	Calculated
4	0.6	0.82	Calculated
5	0.75	1	Calculated
	Other Measures		
	Level 2 Score		
1 (Base)	0.1		
2	0.5		
3	0.5		
4	0.5		
5	1.0		

Table A.3
Level 3 Data for Illustrative Exercise

	Outcomes for Different Definitions of Worst Case		
Option	B.1	B.2	B.3
1 (Base)	0.1	0.1	0.1
2	0.1	0.3	0.3
3	0.1	0.3	0.3
4	0.3	0.5	0.3
5	0.5	0.5	0.3

Table A.4
Cost Data for Illustrative Exercise

Option	Cost ($ millions)
Baseline (Option 1)	0
2	10
3	80
4	160
5	200

Now suppose that, as a first approximation, you think of overall effectiveness as an average of that for Scenarios A and B and as an average of results for best-estimate, best-case, and worst-case variants. Indeed, even in thinking about the worst-case outcome for Scenario B, which has troubling variants, you take an average.

With this background, the exercise is as follows:

- Starting with *Template Builder*, set up PAT appropriately and enter data, recognizing that the data provided here are not in the proper format for PAT. That is, you will have to translate these data into PAT's terms.
- Specify weights, thresholds, and goals appropriately.
- When everything is working, look at the various output sheets to check for any egregious mistakes.
- Recalling that different types of information are separated horizontally on the *Summary* sheet (see Figure A.1), use standard Excel functionality to arrange the sheet so that you can see the scorecard and, immediately adjacent to it, the columns for cost and effectiveness. This will require hiding some columns and creating a two-pane view. To hide columns, select them and choose Column/Hide from the Excel Format menu. To create the two-pane view use the "tug bar" located at the bottom right-hand corner of the display (see Figure A.3).[3]
- Generate the scatter plot of effectiveness versus cost.

If you have done everything correctly, the results should look like those shown in Figures A.4 through A.7.

[3] Microsoft documentation refers to "splitting or freezing panes" when discussing these matters. Precise terminology may differ in different versions of Excel.

Figure A.3
Tug Bar for Viewing Separated Portions of an Excel Spreadsheet

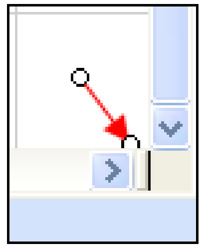


Figure A.4
Summary Sheet Excerpt for Exercise Problem

Measures	Effect. in Scenario A	Effect. in Scenario B	Other Measures		Total Cost: 2010-2030 ($M)	Effectiveness	Relative Cost Effectiveness
	Detail	Detail	Detail	Detail	Detail		
Investment Options	1	1	1				
Baselne (Option 1)					0	0.1	0
Option 2					10	0.23	1
Option 3					80	0.23	0.12
Option 4					160	0.37	0.1
Option 5					200	0.43	0.09

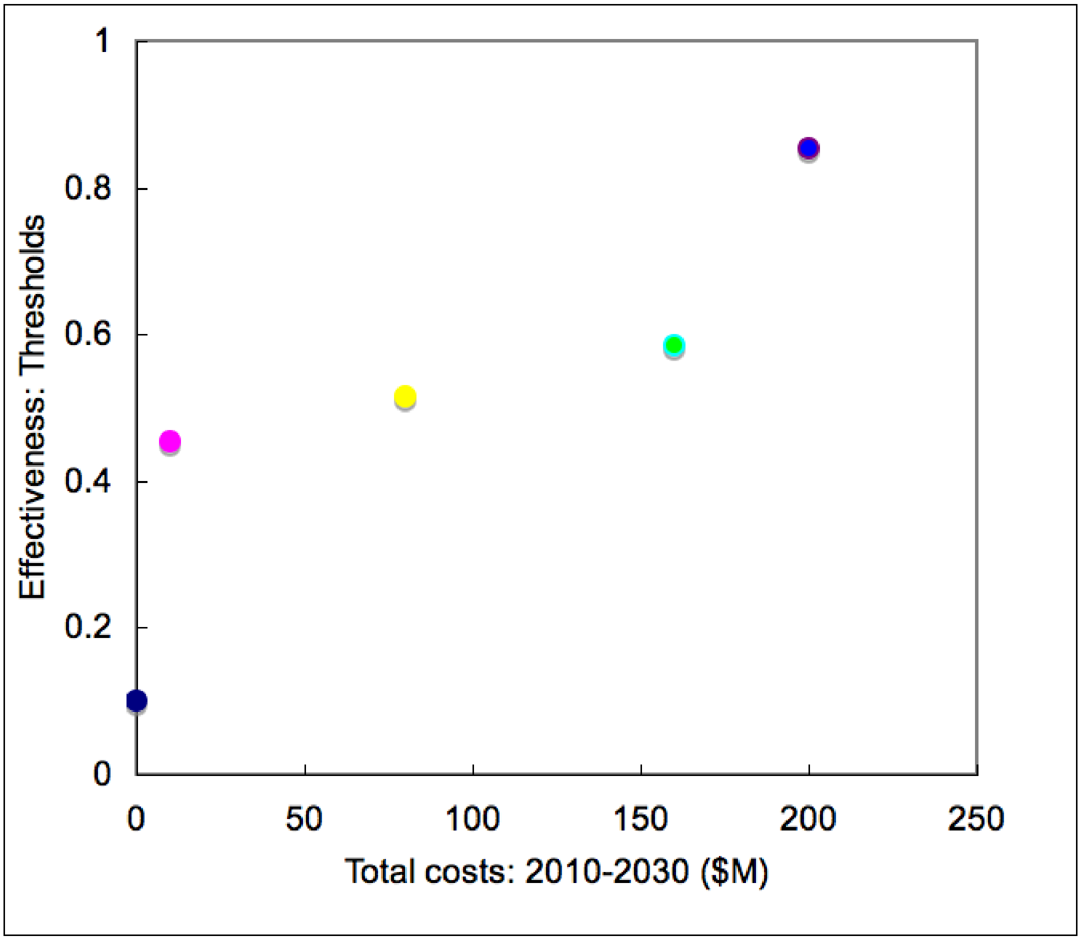
Figure A.5
Level 2 Drilldown for Exercise Problem

Level 1 Measure	Effect. in Scenario B				
Level 2 Measure	Best-Estimate Outcome	Best-Case Outcome (Upside)	Worst-Case Outcome (Risk)	Warning	
Investment Options					Effect. in Scenario B Score
Baselne (Option 1)	0.10	0.10	*0.10*		0.10
Option 2	0.41	0.55	*0.23*		0.23
Option 3	0.45	0.70	*0.23*		0.23
Option 4	0.60	0.82	*0.37*		0.37
Option 5	0.75	1.00	*0.43*	Depends on Technolo	0.43

Figure A.6
Level 3 Drilldown for Exercise Problem

Level 1 Measure	Effect. in Scenario B			
Level 2 Measure	Worst-Case Outcome (Risk)			
Level 3 Measure	Scenario B.1	Scenario B.2	Scenario B.3	
Investment Options				Worst-Case Outcome (Risk) Score
Baselne (Option 1)	0.10	0.10	0.10	0.10
Option 2	0.10	0.30	0.30	0.23
Option 3	0.10	0.30	0.30	0.23
Option 4	0.30	0.50	0.30	0.37
Option 5	0.50	0.50	0.30	0.43

Figure A.7
Scatter Plot of Effectiveness Versus Cost for Exercise Problem

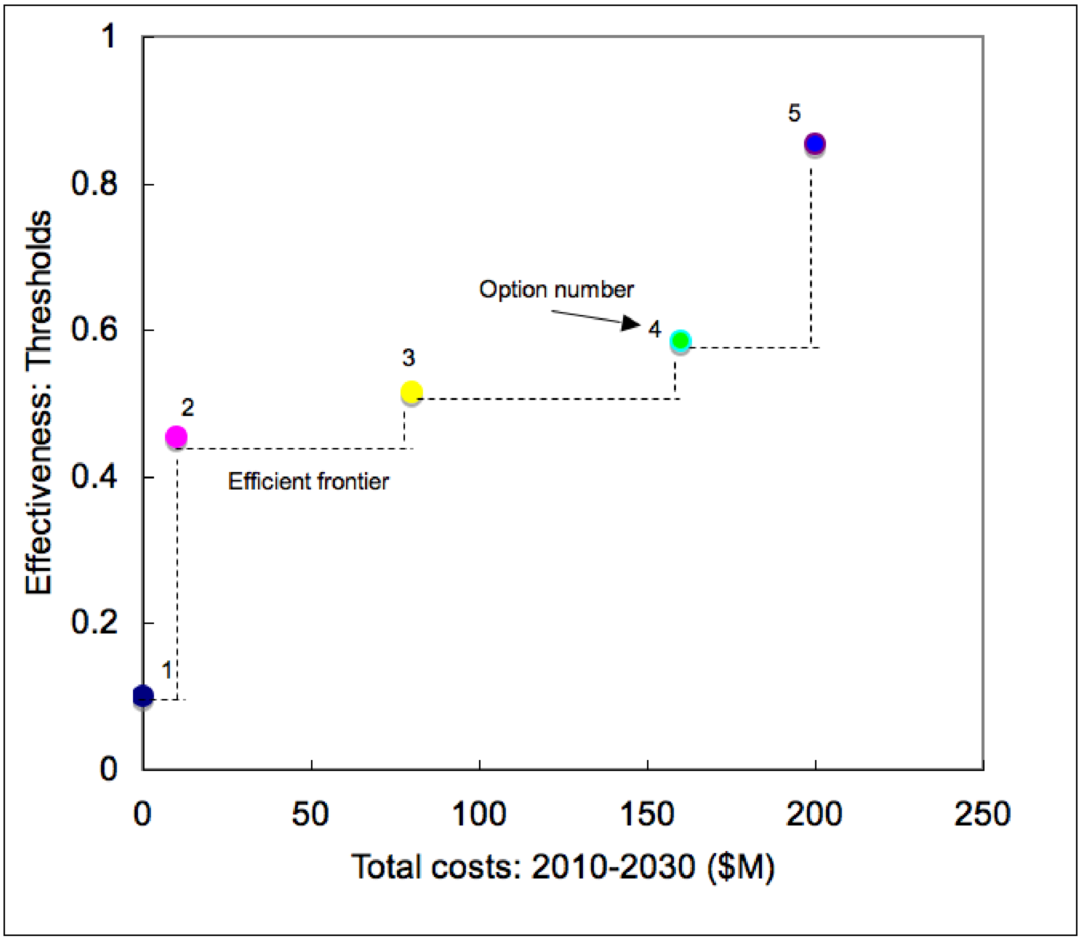


These figures are worth pondering, because they make a point about the relative usefulness of different information. Figure A.4 is a good condensation of information for the analyst: It shows a multiobjective or multicriteria scorecard comparing the options, and it also shows cost and aggregate effectiveness. In our experience, focusing too early on the aggregate effectiveness is a bad idea. Who, after all, really understands what an effectiveness of 0.5 rather than 0.4 means? The scorecards in Figures A.4 through A.6 provide much more information than a single effectiveness number—information needed for decisionmaking.

Effectiveness is useful primarily for summary charts after the decisionmaking has occurred, perhaps for telling the story of effectiveness versus cost, as shown in Figure A.7. The "landscape" of effectiveness versus cost is quite understandable but much more informative than, say, the cost-effectiveness ratio at some particular value of cost. In this example, Option 2 buys quite a lot for modest sums of money ($10 million). Improving results further, however, requires "buying in" to a next big increment of capability. That is, one must spend a good deal more ($80 million) to achieve a sizable jump in effectiveness. Pushing effectiveness to its upper limits, the goal of 1.0, is several times more expensive yet ($200 million). As shown in

the edited version of the chart (Figure A.8), it may be appropriate to connect the points for greater visual clarity. In this case, we assumed that there are no good options between the points shown, so the dashed line constitutes what economists call the "efficient frontier." At any given level of cost (x-axis), there is no option with greater effectiveness than the line, and for any given level of effectiveness (y-axis), there is no option with lower cost.

Figure A.8
Annotated Scatter Plot



APPENDIX B

Transferring Data from an Earlier Workbook

Users working with PAT frequently want to move at least some data from a previous workbook into a new one. Perhaps some errors have been made and results are now confusing. Perhaps one has received an updated version of PAT that corrected some bugs. Or perhaps one just wants to start a number of things fresh. The recommended procedure for copying into a new copy of PAT (a copy of "Clean PAT") is as follows:

- Assuming that the old *Template Builder* is correct, copy and paste data from it first. That is, copy and paste the rows for the investment options and their measures (rows 3 . . .). Then enter or manually set the few remaining items, such as the range of years intended and the cost units (from the related menu). Alternatively, you can copy and paste the entire sheet.
- Run *Template Builder* in the new sheet (i.e., click on Build Sheets). When prompted, say No to the retention of prior data.
- Copy and paste data carefully from the other data sheets, notably some or all of *Perspectives*, *Cost Data*, *Selected Details*, *MRM Level 1 Data*, *Level 2 Data*, and *Level 3 Data*. Be sure to paste into precisely the correct cells.
- Go to *Summary* and choose Update Summary from the Options menu.
- Check the new *Summary* sheet. If you run into trouble, it may be easier to start over than to find the errors and move blocks of data around until everything works. The usual problems result from pasting into the wrong location.

In other instances, a user may want to copy data from one workbook to another after having set up a new structure in *Template Builder*.

The procedure for setting up a new workbook with a partially new structure, carrying over as much data as possible, is as follows:

- Set up the new *Template Builder* in the fresh version of PAT. As usual, be careful in doing so. Run *Template Builder* as above.
- When copying and pasting data from the previous workbook, recognize that the new structure and the old structure do not match. Thus, copying and pasting should be done carefully from block to block where it makes sense. Other data may have to be filled in for the first time (e.g., for a new option or a new measure).
- As an alternative, the user can copy and paste full data from a previous sheet and then edit by moving columns and rows around until they are in the right place, also assuring

that control parameters are set correctly. Although this can be done, it is more error-prone than the deliberate procedure suggested above.

The most important advice is probably to perform any data transfer slowly, methodically, and carefully, rather than doing it quickly and trying to catch and correct errors afterward. And, of course, have backups.

APPENDIX C

Editing and Neatening

It will often be necessary to edit PAT sheets, either for clarity or to produce an output display suitable for use in a viewgraph or document. Since PAT is implemented as an Excel spreadsheet file, all of Excel's ordinary features apply. However, the following few hints may prove helpful:

- To move a button or control panel, use Control-Select to avoid triggering the action.
- Use Control-Select, followed by the Ungroup command, to move items within a larger block (e.g., one menu item among a group of control panels).[1]
- Use Excel's custom formats for charts to achieve some consistency. Unfortunately, such customization affects only some chart attributes, so repetitive editing may still be necessary from chart to chart. Further, all formatting is lost when charts are regenerated. Unclick the Auto-Update Chart checkbox to avoid losing chart formatting when switching between sheets.
- To annotate charts with text-box notes (e.g., labeling curves or specifying assumptions), consider copying and pasting an entire set of notes into an extra worksheet so that they can be retrieved and reused. Regenerate the chart, copy and paste the previous notes, and then move them around as appropriate.
- Do not hesitate to use custom worksheets to do "normal" Excel charting, drawing upon PAT's input or output data as needed. In some cases, PAT's built-in charts are not what the user is seeking, and it is counterproductive to try to work around them.

[1] We modified PAT to provide compatibility with Excel 2007, but our experience with Excel 2007 is limited, and other side effects of Microsoft's major changes may occur. In particular, we suggest that users avoid moving menus and perhaps other spreadsheet objects, or at least save before attempting to do so. And, as mentioned earlier, PAT will not work in Excel 2008 (Mac). Macintosh users should retain Excel 2004 (even if they otherwise upgrade to Office 2008) or use a virtual machine such as Parallels Desktop or VMware Fusion. Both solutions have been quite satisfactory, in our experience.

References

Bracken, Jerome, Moshe Kress, and Richard Rosenthal, *Warfare Modeling,* New York: Wiley, 1995.

Cohen, William, *Report of the Quadrennial Defense Review,* Washington, D.C.: Department of Defense, 1997.

——— (ed.), *New Challenges in Defense Planning: Rethinking How Much is Enough,* Santa Monica, Calif.: RAND Corporation, MR-400-RC, 1994. As of September 2, 2009:
http://www.rand.org/pubs/monograph_reports/MR400/

Davis, Paul K., *Analytic Architecture for Capabilities-Based Planning, Mission-System Analysis, and Transformation,* Santa Monica, Calif.: RAND Corporation, MR-1513-OSD, 2002a. As of September 2, 2009:
http://www.rand.org/pubs/monograph_reports/MR1513/

———, "Synthetic Cognitive Modeling of Adversaries for Effects-Based Planning," *Proceedings of the SPIE*, Vol. 4716, No. 27, 2002b, pp. 236–250.

Davis, Paul K., and James H. Bigelow, *Experiments in Multiresolution Modeling (MRM),* Santa Monica, Calif.: RAND Corporation, MR-1004-DARPA, 1998. As of September 2, 2009:
http://www.rand.org/pubs/monograph_reports/MR1004/

———, *Motivated Metamodels: Synthesis of Cause-Effect Reasoning and Statistical Metamodeling,* Santa Monica, Calif.: RAND Corporation, MR-1570-AF, 2003. As of September 2, 2009:
http://www.rand.org/pubs/monograph_reports/MR1570/

Davis, Paul K., James H. Bigelow, and Jimmie McEver, *Exploratory Analysis and a Case History of Multiresolution, Multiperspective Modeling,* Santa Monica, Calif.: RAND Corporation, RP-925, 2001. As of September 2, 2009:
http://www.rand.org/pubs/reprints/RP925/

Davis, Paul K., David C. Gompert, and Richard L. Kugler, *Adaptiveness in National Defense: The Basis of a New Framework,* Santa Monica, Calif.: RAND Corporation, Issue Paper IP-155, 1996. As of September 2, 2009:
http://www.rand.org/pubs/issue_papers/IP155/

Davis, Paul K., and Richard Hillestad, "Families of Models That Cross Levels of Resolution: Issues for Design, Calibration, and Management," *Proceedings of the 1993 Winter Simulation Conference*, 1993.

Davis, Paul K., Richard Hillestad, Duncan Long, Paul Dreyer, and Brandon Dues, *Reflecting Warfighter Needs in Air Force Programs*, Santa Monica, Calif.: RAND Corporation, forthcoming.

Davis, Paul K., and Reiner Huber, *Variable Resolution Combat Modeling: Issues, Principles and Challenges*, N-3400-DARPA, 1992. As of September 2, 2009:
http://www.rand.org/pubs/notes/N3400/

Davis, Paul K., Stuart Johnson, Duncan Long, and David C. Gompert, *Developing Resource-Informed Strategic Assessments and Recommendations*, Santa Monica, Calif.: RAND, MG-703-JS, 2008. As of September 2, 2009:
http://www.rand.org/pubs/monographs/MG703/

Davis, Paul K., Richard L. Kugler, and Richard Hillestad, *Issues and Options for the Quadrennial Defense Review (QDR),* Santa Monica, Calif.: RAND Corporation, DB-201-OSD, 1997. As of September 2, 2009:
http://www.rand.org/pubs/documented_briefings/DB201/

Davis, Paul K., Jonathan Kulick, and Michael Egner, *Implications of Modern Decision Science for Military Decision-Support Systems,* Santa Monica, Calif.: RAND Corporation, MG-360-AF, 2005. As of September 2, 2009:
http://www.rand.org/pubs/monographs/MG360/

Davis, Paul K., Jimmie McEver, and Barry Wilson, *Measuring Interdiction Capabilities in the Presence of Anti-Access Strategies: Exploratory Analysis to Inform Adaptive Strategies for the Persian Gulf,* Santa Monica, Calif.: RAND Corporation, MR-1471-AF, 2002. As of September 2, 2009:
http://www.rand.org/pubs/monograph_reports/MR1471/

Davis, Paul K., Russell D. Shaver, and Justin Beck, *Portfolio-Analysis Methods for Assessing Capability Options*, Santa Monica: Calif.: RAND, MG-662-OSD, 2008. As of September 2, 2009:
http://www.rand.org/pubs/monographs/MG662/

Dreyer, Paul, and Paul K. Davis, *The Portfolio Analysis Tool for Missile Defense (PAT-MD): Methodology and User's Manual,* Santa Monica, Calif.: RAND Corporation, TR-262-MDA, 2005. As of September 2, 2009:
http://www.rand.org/pubs/technical_reports/TR262/

Dunn, William N., and Rita Mae Kelly, *Advances in Policy Studies Since 1950 (Policy Studies Review Annual) (V. 10),* Edison, N.J.: Transaction Publishers, 1991.

Gates, Robert, "A Balanced Strategy: Reprogramming the Pentagon for a New Age," *Foreign Affairs*, January/February 2009.

Goeller, B. F., et al., *Policy Analysis of Water Management for the Netherlands,* Vol. I*, Summary Report,* Santa Monica, Calif.: RAND Corporation, R-2500/1-NETH, 1983. As of September 2, 2009:
http://www.rand.org/pubs/reports/R2500.1/

Graham, John, "Valuing the Future: OMB's Refined Position," *University of Chicago Law Review*, Vol. 74 (Winter), 2007.

Hillestad, Richard, and Paul K. Davis, *Resource Allocation for the New Defense Strategy: The DynaRank Decision Support System,* Santa Monica, Calif.: RAND Corporation, MR-996-OSD, 1998. As of September 2, 2009:
http://www.rand.org/pubs/monograph_reports/MR996/

Hitch, Charles J., and Roland N. McKean, *Economics of Defense in the Nuclear Age,* Cambridge, Mass.: Harvard University Press, 1965.

Kaplan, Robert S., and David P. Norton, *The Balanced Scorecard: Translating Strategy Into Action,* Cambridge, Mass.: Harvard Business School Press, 1996.

Keeney, Ralph, *Value-Focused Thinking: A Path to Creative Decisionmaking,* Cambridge, Mass.: Harvard University Press, 1992.

Keeney, Ralph, and Howard Raiffa, *Decisions with Multiple Objectives: Preferences and Value Trade-Offs,* Wiley, 1976.

Kirkwood, C. W., *Strategic Decision Making: Multiobjective Decision Analysis with Spreadsheets*, Belmont, Calif.: Duxbury Press, 1997.

Miller, Drew, "Decision Support Systems: A Way to Improve Cost Effectiveness in the Department of Defense," *Armed Forces Comptroller Magazine*, Vol. 52, No. 3, 2007.

National Academy of Sciences, *Post-Cold War Conflict Deterrence,* Washington, D.C: National Academies Press, 1996.

National Research Council, *Defense Modeling, Simulation, and Analysis: Meeting the Challenge*, Washington, D.C.: National Academies Press, 2006.

Natrajan, Anand, and Paul F. Reynolds, "Resolving Concurrent Interactions," *Distributed Interactive Simulation and Real-Time Applications (DIS-RT) Proceedings*, 2001, pp. 85–92.

Parnell, Greg, "Value-Focused Thinking Using Multiple Objective Decision Analysis," in *Methods for Conducting Military Operational Analysis: Best Practices in Use Throughout the Department of Defense,* Alexandria, Va.: Military Operations Research Society, 2006.

Raiffa, Howard, *Decision Analysis: Introductory Lectures on Choices Under Uncertainty,* Reading, Mass.: Addison-Wesley, 1968.

Ratliff, Thomas, "A Comparison of Dodgson's Method and the Borda Count," *Economic Theory*, Vol. 20, No. 2, 2002, pp. 357–372l

Reynolds, Paul F., Anand Natrajan, and Sudhir Srinivasan, "MRE: A Flexible Approach to Multi-Resolution Modeling," *Proceedings of the Eleventh Workshop on Parallel and Distributed Simulation,* Lockenhaus, Austria, 1997.

Willis, Henry H., James Bonomo, Paul K. Davis, and Richard Hillestad, *Capabilities Analysis Model for Missile Defense (CAM-MD): User's Guide,* Santa Monica, Calif.: RAND Corporation, TR-218-MDA, 2006 (not available to the general public).

Yilmaz, L., and T. Ören, "Prospective Issues in Simulation Model Composability: Basic Concepts to Advance Theory, Methodology, and Technology," *The Modeling and Simulation Information Analysis Center (MSIAC) e-Journal*, 2004.

Zeigler, Bernard, Herbert Praenhofer, and Tag Gon Kim, *Theory of Modeling and Simulation,* 2nd ed., *Integrating Discrete Event and Continuous Complex Systems,* San Diego, Calif.: Wiley, 2000.